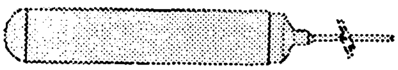
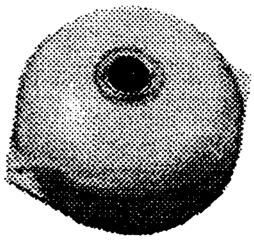
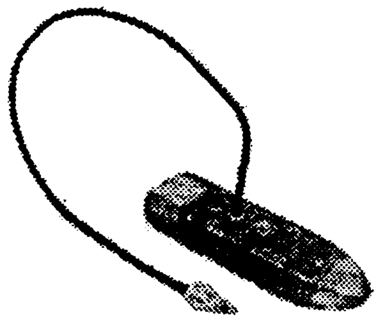
NOAA Technical Memorandum NMFS-SEFSC-357

# ARCHIVAL TAGS 1994: PRESENT AND FUTURE[1]

## Archival Tag Working Group
## 45th Annual Tuna Conference
## Lake Arrowhead, CA
## May 23-26, 1994







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# NOTICE



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**Abstract**

We provide annotated summaries of the scientific contributions given in a special session on archival tags, held in conjunction with the **45th Annual Tuna Conference** at Lake Arrowhead, California, 23-26 May 1994. Comments are also transcribed from participants of a round-table discussion on archival tag technology and development. We summarize the state of tag development and make recommendations for improving the tag. We acknowledge that exciting advances in archival tag technology have occurred, particularly in data logging and geolocation. However, we emphasize three general research needs: 1) increased latitudinal accuracy to the geolocations, 2) additional means of data retrieval other than conventional tag recovery, and 3) improved methods of fish collection, handling, and tag attachment that minimize fish trauma.

A. Peter Klimley, Rich W. Brill,
and Kim Holland (Rapporteurs)
Eric D. Prince (Chairman)

**Summaries of Scientific Presentations**[6]

(Chairman: Eric D. Prince)

**Arnold, G.P.: First results with the Lowestoft archival tag: migratory tracks of plaice in the Southern North Sea.**

A description of the archival tag developed at the Fisheries Laboratory, Lowestoft, UK. was provided. The tag is based upon hybrid microelectronics technology and contains a programmable microcontroller, a mass data store, and an analogue sensor board. A total of 90 mature female plaice from the southern North Sea were fitted with archival tags in 1993 and 1994 using an external method of attachment. Data were presented from nine tags on plaice at large for periods ranging from 3 to 146 days. These tags provided a total of 462 days of data.

**Ekstrom, P.A.: Archival tags: present and future.**

An overview of archival tag technology developed at Northwest Marine Technology, including applications and limitations, was presented and followed by a discussion of future capabilities. Miniaturization of electrical components and batteries would result in substantially smaller and "smarter" archival tags in the future. However, satellite retrieval of data stored in the tag is unlikely in the near future.

**Fralick, R.D. and P.A. Ekstrom: Engineering tests of Northwest Marine Technology's archival tag.**

A comprehensive description was given of tests designed to illustrate the various capabilities of the Northwest Technology archival tag. The accuracy of

[6]Only presentations that dealt directly or indirectly with archival tags were included in this review.

measurements of depth and temperature made with the tag's sensors was verified by comparison with independent measurements of pressures and temperatures simulated in the laboratory. The ability of the light sensor and clock to accurately determine longitude was also verified in field tests consisting of large geographic displacements of the tag.

**Gunn, J., T. Polacheck, T. Davis, M. Sherlock, and M. Nicolau: The development and use of archival tags to study the movement, behaviour and physiology of the southern bluefin tuna, *Thunnus maccoyii*.**

The archival tag developed by Zelcon Technic Pty. Ltd. for CSIRO was described. This tag is capable of measuring and storing data on swimming depth, body and surrounding water temperature, and light levels (for determining geolocation). The return rates of dummy tags, placed externally and internally, were compared on wild young-of-the-year tuna ($\leq$25 kg) -- the latter mode of attachment was superior. Preliminary results were presented based on the deployment of 180 archival tags placed on juvenile tuna in South Australia in 1994. Geolocations recorded and stored in a tag attached to a southern bluefin tuna swimming within a cage were compared to positions determined independently for the cage as it was towed at the surface in the open ocean. Archival tags were also successfully attached to whale sharks, *Rhincodontus typus*, off West Australia by inserting a dart through the dorsal fin.

**Klimley, A.P. and W.J. Mangan: Optimizing positional accuracy of archival tags with irradiance and magnetic sensors.**

The longitudinal accuracy of archival tags was shown to depend on the temporal resolution with which sunrise and sunset can be determined. The change in light at dusk was described from continuous measurements of irradiance over eight 40 nm wide bands, and suggestions were given on how to relate level changes more closely to the time of sunset. The capabilities of two types of magnetic sensors, magnetoresistive and magneto-optic, for determining latitude were evaluated. The latter sensor was favored because it does not generate a magnetic field that could interfere with the fish's ability to sense the earth's field while navigating. GEOMAG software was described that would determine a latitude coordinate based upon the International Geophysical Reference Field (IGRF), given a measurement of total field intensity at sea surface and a longitude coordinate based upon irradiance measurements.

**Klimley, A.P. and W.J. Mangan: "Listening stations" for retrieval of data from archival tags.**

The need to increase the likelihood of retrieving data from archival tags placed upon highly migratory species was emphasized. "Listening stations," moored at locations to which fish return, could interrogate the tags with an ultrasonic modem, and transmit by VHF radio directly to shore-based stations or via satellite uplink. First-generation stations are being deployed at Fish Aggregations

Devices (FADs) around Hawaii to detect the presence of yellowfin tunas tagged with individually coded ultrasonic transmitters. Discussed were both single and multi-frequency modems that could transmit data from archival tags to second-generation listening stations.

**Nishida, T.: Development and application of archival tags in Japan.**

Three Japanese research teams have been developing archival tags, including the: 1) Kyoto University, 2) National Institute of Polar Research, and 3) National Research Institute Far Seas Fisheries (NRIFSF). These tags have one to three channels and measure depth, temperature, and/or light. These tags have been applied to fishes, sea turtles, sea birds, and seals. Although archival tags have not yet been applied by Japanese scientists to highly migratory species, there are plans to conduct archival tagging experiments with northern bluefin tuna.

**Prince, E.D.: Tag performance research at the Southeast Fisheries Center and attachment problems associated with archival tags.**

Through the Cooperative Game Fish Tagging Program (GCFTP) of the Southeast Fisheries Center, 160,000 highly migratory species, mainly tuna and billfishes, have been tagged and released with stainless steel streamer tags since 1954. Recapature rates have varied from a high of 12% for bluefin tuna (*Thunnus thynnus*) to a low of 0.5% for blue marlin (*Makaira nigricans*). These recapture rates suggest that traditional tagging techniques appear to be an inefficient method of data retrieval for archival tags based upon the low recapture rates (<4%) observed for most migratory species. A more biologically compatible tag was described consisting of a medical grade nylon anchor attached to a streamer using heat shrink tubing. Tests are being conducted to establish whether the new tags have better shedding and holding characteristics than tags currently in use. If successful, this anchor might be used with archival tags.

## Round-table Discussion

A. Peter Klimley, Rich W. Brill,
and Kim Holland (Rapporteurs)
Eric D. Prince (Moderator)

The remarks of participants during the round-table discussion were reproduced, in part, from a video tape of the session. However, the comments were at times abbreviated or amplified based upon the discretion of the authors.

| *Participant* | *Remarks* |
|---|---|
| Gunn: | Two improvements in tag design would be: (1) reduction in size and (2) an increase in the capacity for data storage. |
| Sibert: | The fish's location may not always be of primary interest to the tag user. For instance, a physiologist might be interested in internal body temperature. |

Stone: To those of us managing the bluefin tuna fisheries in the Atlantic, it is most important to know the pathways used by individuals of this species. Yet unanswered is whether there are one or two separate stocks for this species. The archival tags that record routes of travel could be used to determine whether individuals regularly cross the Atlantic in either an eastward or westward direction.

Klimley: It is essential that we strive to increase the accuracy of the positioning ability of the archival tags. Just making it small will not make it useable with smaller, less mobile species of fish. A latitudinal error of 120-240 nautical miles (with less accuracy in tropical waters) may be tolerable with the pan oceanic movements of temperate bluefin tunas, but not for the oceanic movements of some tropical migratory species or for the more localized movements of coastal species regardless of whether they are tropical or temperate.

Gunn: There is always a downside to waiting for future developments before moving - the future always appears brighter! However, when considering the development and application of new technology, advances cannot be made without developing and evaluating a sequence of generations of hardware and software or without thorough baseline studies. In the case of archival tags, rapid advancement of hardware and software will only come when experiments were conducted across a broad range of species with available technology. Manufacturers cannot be expected to underwrite all of these phases in the development of a "better" or "perfect" tag.

Holland: I am worried about the light sensing stalk on the tag that passes through the body cavity of the fish. Drag from passing water would pull the stalk back each time the fish suddenly accelerates? Would this not irritate the fish?

Gunn: The tear-shaped end of the stalk on the CSIRO tag was designed so that the stalk remains rigid and does not wobble as a fish swims.

Prince: A related concern is the tag's mode of attachment. We have recovered fish after many years with stainless steel dart tags still implanted in their musculature. A messy wound often exists where the tag penetrates the skin. The new nylon anchor tags appear to cause less irritation yet have more holding power than the stainless steel anchors.

Holland: Handling is a problem with tunas and billfish. Have there been any advances in handling procedures?

Brill: Anesthetization of tunas and billfish is still problematic.

Unid.: We were able to transfer yellowfin and skipjack back to the laboratory by flushing their gills with a solution of salt water and MS 222. As the fish became more sluggish, we removed the hose dispensing the solution into the mouth of the fish.

Holland: Does the agitated state of the fish at the side of the boat prevent the use of this technology.

Block: Depends upon the size and species of the fish. Internal implantation would be difficult in a larger fish -- external implantation is almost a must.

Prince: Billfish (marlin, sailfish, spearfish, and swordfish) are particularly difficult and dangerous to handle at boatside because of their upper bill. We have been able to bring small sailfish of no more than 45 lbs into the boat and inject them with oxytetracycline, but the larger blue marlin are too dangerous. Even juvenile blue marlin of about 100 lbs are still to large to deal with.

Gunn: Putting an anesthetized fish back in the water without an antidote is risky. I like to release a fish where it can return to the same school. By prolonging the time of tag attachment with an anesthetic, one is likely to release the fish where it can not find its school.

Block: Larger fish should not be anesthetized. Handling larger fish out of the water is not only dangerous to the scientist, but also can cause internal injuries to the fish.

Block: Would people actually pay for tags to place on individuals of a species with only a 1-3% rate of tag return?

Gunn: Yes, one return of an archival tag from a prized species such as the black marlin might actually be worth the $100,000 cost of a hundred tags.

Pepperell: For a species like the black marlin which appear to return to specific locations along the barrier reef, the listening station concept might work, substantially increasing the number of tags from which data could be retrieved.

Klimley: Our knowledge of the movements of fish, of course, is based largely upon a single release and recapture. This technique in itself prevents one from observing the same individual several successive times in the same location. To detect homing behavior using conventional tagging, you have to be quite lucky and recapture the fish at just that instant in its extensive travels when it returns to the prior site. Fishes may home more often than we presently think. Archival tags can answer this question by providing detailed tracks of the routes fish travel.

Klimley: Is there any evidence of homing in tunas and billfishes in the South Atlantic?

Prince: We have evidence of routes along which fish migrate -- homing is another thing. For instance, white marlin inhabiting waters along the southeast United States coast during the summer move down into the warmer tropical waters off South America as water temperatures start to cool in the fall and during the winter. A bycatch of as many as 20 billfish per 20 mile set are caught on Venezuelan long-line boats that target tuna because billfish are concentrated in this area during the winter. Then, the fish disperse into more northern temperate waters during the summer as water temperatures increase. These general movement patterns are verified many times over by the results of our conventional tagging program. These programs only provide start and end points of movement -- the route a fish travels can only be inferred at best.

Gunn: Regarding the "listening stations," what if the fish swims out of the range of the monitor before the entire contents of the tag is disgorged.

Klimley: Part of the file may be retrieved during the first pass; the rest during a second. The multifrequency modems transmit information relatively quickly, 1200 bps, a rate at which the present contents of the tags would be passed in four minutes. An alternative to the "listening station" would be a radio link that would transmit the tag's entire contents to a satellite. This tag would release from the fish at a preset time.

Prince: Such methods would be necessary for a species such as the blue marlin for which the rate of recapture in the Atlantic is only 0.5% (Table 1).

Kleiber: The data reduction approach of Northwest Marine Technologies, Inc. might be advantageous if the stored information needs to be passed from tag to "listening station" over a relatively short period. It is nice to get a fine-resolution record of the up and down movements of the fish throughout the day, but if your choice is to get one position of the fish per day or nothing, you might have to sacrifice some of the complete data set.

Block: Each user should be provided with options to chose just that data acquisition mode that fits his or her individual requirements.

Holland: It gets back to John's (Gunn) rhetorical question posed in the beginning of this session. What do we want? The most important question is "Where did they go?"

Block: If your fish is at a low latitude, how accurate is the tag at determining the fish's position?

Ekstrom: There is a problem with determining latitude when you are in the tropics near the equator. The water temperature is uniformly warm and the magnetic field changes less.

Kleiber: Some models in which the positional data would be used have a coarse geographic resolution of 5 degrees -- the low latitudinal accuracy might not affect these models significantly.

Ekstrom: There are two important questions. The first is: "What can you do with the technology that is available now?" The second is: "What do you want next? At some point, I would like to hear what you would like in the future.

Block: Of course, we would like a tag that would pop to the surface and transmit its data to a satellite. What are you going to do with a 2% recovery rate? It's too low!

Prince: The four percent (or less) recapture rate for highly migratory species in our tagging program is based upon tagging primarily by recreational and commercial fishermen, not scientists. We believe this contributes to the low recapture rates.

Laurs: Most studies, even by professionals, have resulted in no more than a 2% recovery rates for commercially important species of fishes.

Block: This is a major obstacle to the use of archival tags.

Gunn: If the cost of deploying these tags is low relative to deploying large numbers of conventional tags or tracking individual fish with sonic tags with a research vessel, perhaps the 2% return rate is not such a bad return for the effort.

Kleiber: The cost per tag during the extensive skipjack tagging program was about $200 per recovery. I took the cost of an archival tag, at that time $2,500, and divided this amount by the number of daily positions it would log after being at sea for several years. The cost per daily position was the same as that for the recovery of a conventional tag.

Klimley: It is not true that each daytime point can be equated to a tag recovery. From conventional tags we have an estimate of the movements of many fish; from an archival tag we have the track of a single fish.

Kleiber: Rather than comparing the price of a single inexpensive conventional tag to an expensive archival tag, the total cost of running one tagging program should be compared to running the other.

Gunn: This slide demonstrates that the closer that you get to the equator, the harder it is for you to determine the position of the fish based upon daylength. It does not vary much between 15° S. and 15° N. It doesn't matter how good you are at estimating daylength, you are still going to have a large positional error, highest near the equator. We will have to tolerate this unless Pete (Klimley) gets his magnetic sensor up and running. These 3-D plots are from a booklet on geolocation available from Wildlife Computers, Inc. If you are interested in learning how to determine position from data from an archival tag, I would recommend that you consult this booklet which is written in simple English. High error terms occur at those latitudes at those times of the year when day and night are of the same duration. I truly believe that before an electromagnetic sensor comes on line that you will get no more than two or three or four degrees of latitudinal accuracy. However, there is no such problem with longitude. When the irradiance sensors and algorithms are perfected, you may get the longitudinal accuracy down to tenths of degrees.

Holland: An external tag would appear to me unlikely to last very long on a fish.

Gunn: We are testing the concept of an external tag.

Kleiber: Has anyone here had experience with restraining large fish?

Klimley: Sharks are regularly transported in large rectangular tanks, often with foam on the sides, usually with a bilge pump for circulating the water and an oxygen tank for oxygenating the water. You pull the shark into a sling of canvass fastened between two handles at the side of the boat. The sling with the shark is then lifted over the gunwale of the boat and allowed to rest at the bottom of the rectangular box. The fish is handled in a small boat, not a large research vessel with it's high freeboard. Has anyone here used this technique with tunas or billfishes?

Prince: We have brought small sailfish aboard but not larger billfish, even in a sling. I would hesitate to try that with a larger marlin or swordfish. Again, using an external method of attachment could avoid the problems with the larger, more dangerous species.

Klimley: Another consideration is tag color. We had a very low rate of encounter with ultrasonic tags one year. Their color coding made them quite conspicuous and they tended to wobble when the shark accelerated. I eventually did see another shark chase a shark when it accelerated upon tagging and bite the transmitter. When returning to the surface, I recovered half of the transmitter with tooth marks indicative of the bite. This transmitter was coded by three white bands that were particularly conspicuous, flashing as the shark accelerated. It might be prudent to try to match the color of these tags to the coloration of the fish.

Holland: Is there a problem with fouling affecting the ability of the tag to sense light?

Pepperell: The conventional tags that we use on black marlin become extremely fouled over time.

Unid.: There is now available a paint made from a derivative of chili peppers that appears to be even more effective than traditional anti-fouling paints with a tributyl tin base.

Laurs: Fouling may be more of a problem in warmer waters.

Gunn: The application of a colorless paint would not affect sensor performance.

Fierstine: The Tuna Commission has had tags on yellowfin tunas in the tropics for periods of two to three years without much fouling.

Prince: In many cases the tags on billfish are covered with marine growth and barnacles in a surprisingly short time (a couple of months). In other cases, tags placed in billfish at liberty for several years are fairly clean.

Block: External attachment will be a necessity with the larger fishes that are not easily restrained.

Gunn: In many respects, it is easier to make an external attachment than internal one.

Holland: The mode of attachment should first be evaluated either in fish cages in South Australia (e.g., John Gunn of CSIRO) or in a tank at Kewalo Basin (e.g., Pierre Kleiber of NMFS). The empirical approach to testing the tags and sensors, advocated by Klimley and Gunn, is strongly recommended. The growth of fish in the Kewalo tanks slows as fish grow larger so that the cages in South Australia may be a superior test environment.

Stone: The answer to whether the government would provide large amount of funds necessary to obtain a few returns is directly related to the importance of the management decisions that the resulting data would help answer. We would very much be interested in knowing whether swordfish do penetrate into low latitudes. A question of this importance might merit the funds necessary to dispense a hundred archival tags. The recommendations of a round-table session such as this or peer review will go a long way toward convincing the funding sources. The results of this workshop could be used to go to fisheries managers and convince them that a large amount of funds be directed toward the implementation of this technology.

Brill: The problem here is that if that one swordfish that is caught did not go south, yet the others went in that direction, the fisheries managers would be mislead.

Stone: Although the archival tags at their present state may not unequivocally answer such a question, they certainly will have a major impact in the future, especially if used in conjunction with other methodologies.

Sibert[7]: My concern is that these things have been oversold, particularly to fisheries managers. As scientists we should view them as research tools and define clearly what scientific objectives we can achieve using archival tags. I believe that we need to do two things in the near future. First, we need to deploy some devices of the current generation, acknowledging that they are far from perfect, and find out exactly what they can and cannot do. How inaccurate are latitude estimates in a freely swimming and diving animal? This is a very important step. It signals to manufacturers that we are serious, and encourages them to keep up their development efforts. It provides performance data on which to base designs for tags which might actually be useful. It also gives us experience with attachment and recovery problems. The second thing we need to do is to build and test prototypes incorporating magnetic field sensors and remote interrogation mechanisms. If we deploy tags, as suggested above, on large animals (e.g., sharks, sea turtles, and swordfish), we can use that experience to deploy and test prototypes which will certainly be too large for a small tuna to carry.

Klimley: With regard to sea turtles which breathe at the surface, the archival tag could be paired with a satellite transmitter to independently verify the accuracy of the former's position determinations.

**Session Summary**

An archival tag is a microprocessor-based recorder that has sensors to measure either behavioral, physiological, or environmental properties and stores the measurements, or processed subsample of them, in an electronic memory in the tag until the data are later removed. An archival tag may simply store

[7]Concern raised upon reading early draft of Technical Memorandum.

measurements, or use the measurements to obtain a record of the daily geographic positions of the tagged fish. The latter ability is termed "geolocation." Participants at the workshop were surprised at the recent progress made in CSIRO in Australia, MAFF Directorate of Fisheries Research at Lowestoft, U.K. and Northwest Marine Technologies, Inc., U.S.A.

Geolocating archival tags determine longitude using a method similar to that used by ancient sailors to navigate in the ocean. They found their longitude from the difference between the apparent time when the sun was at its highest point at their present location and the time at a reference location (e.g., Greenwich, England). This time differential was measured with a chronometer. The archival tag also has very accurate internal clock, which may be initialized to Greenwich Mean Time (GMT). However, the tag is unable to find noon by the position of the sun because the tagged fish is underwater. Alternatively, the tag records the times of sunrise and sunset by means of a sensor that detects the rapid change in light occurring at dawn and dusk. During astronomical twilight, light intensity, integrated across a spectrum of 400-700 nm, decreases seven log units (Figure 1). This large and rapid change dwarfs the fluctuations of a single log unit or less which occur when clouds pass in front of the sun. For example, the archival tag available from Wildlife Computers calculates the times of sunrise and sunset to be 50% of the total light of the light level curve (Figure 2). These points on the plot estimate those times when the sun is 90.83 degrees from its

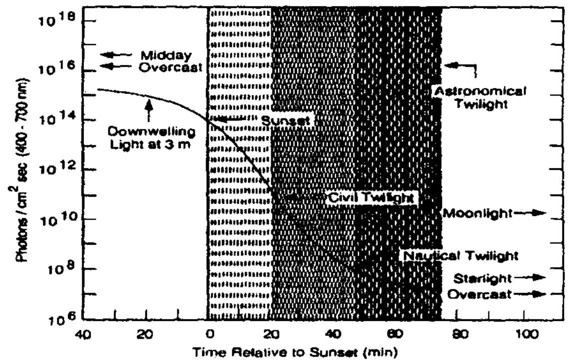


**Figure 1.** Change in irradiance intensity integrated across spectrum of 400-700 nm occurring at sunset. Note that irradiance intensity decreases seven log units. Redrawn from Munz and McFarlane (1973). The set of the sun defined by the angle between its zenith and the lower rim of the sun's disk of 90°50', Civil Twilight by 96°, Nautical Twilight by 102°, and Astronomical Twilight by 108° (see Appendix A).

zenith, or the upper rim of the sun is just "peeking" above the horizon. On the 21 June record shown from an archival tag of Wildlife Computers, the sun's rise occurred at an the apparent time of 13:52:07 (see solid vertical line second from left) and the set at 04:07:35 (see solid line second from right). Note the dotted horizontal lines are halfway between the dotted lines indicating lowest and highest sections of the light curve. The start of dawn and end of dusk were calculated to be 5% of the total height of the light level curve. These points estimate those times when the sun is 96° from zenith below the horizon (= civil twilight). On the record, dawn began at 13:00:00 (see solid line to left of line indicating sunrise), and dusk ended at 4:49:49 (see solid line to right of the line indicating sunset). It should be

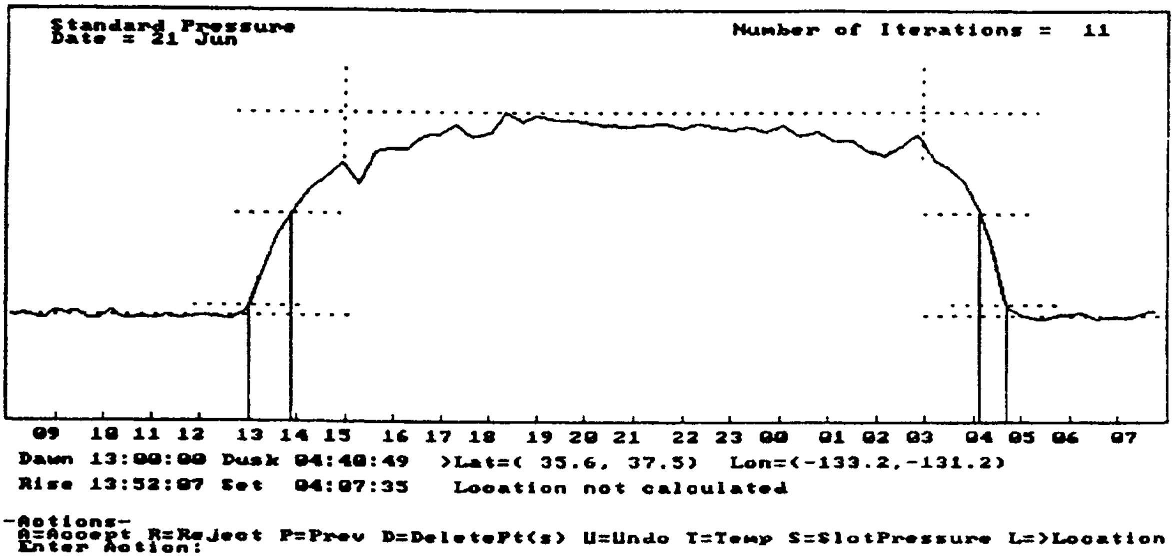


**Figure 2.** Curve of irradiance intensities measured over the period of a day during the Summer Solstice by an archival tag of Wildlife Computers. The lowest and highest horizontal dotted lines indicate the nighttime and daytime parts of the curve. The dotted lines just above the lowest dotted lines estimate when dawn starts and dusk ends, and the similar lines halfway betwen the lowest and highest lines estimate the times of sunrise and sunset. The graph shows the best location calculation for an animal around the mid-30° latitude area. Taken from Hill (1991).

noted that the error term is related to the interval between measurements of irradiance. The interval at which irradiance will be measured in the future will likely be shorter than the 8 min interval used by Hill (Figure 2) in these initial prototypes of archival tags. This reduction in measurement interval will result in an increase in geographical accuracy. In addition, the horizontal dotted lines corresponding to these points on the irradiance curve are 5% of the distance between the dotted lines corresponding the lowest and highest parts of the curve. Notice that the placement of the point for the end of nautical twilight on the archival tag of Wildlife Computers is very similar curve of broad band irradiances measured by Munz and McFarland (see Figures 1 & 2). Formulas exist to calculate dawn, sunrise, sunset, and dusk based upon location (see excerpt from Almanac for Computers 1990 in Appendix A). The formulas are also discussed in Bowditch (1984). The terms can be re-arranged to solve for latitude and longitude. The times of these celestial events, dawn and dusk being preferred for the greater reliability with which they can be approximated, are entered into algorithms to determine the time of local-apparent-noon from that longitude.

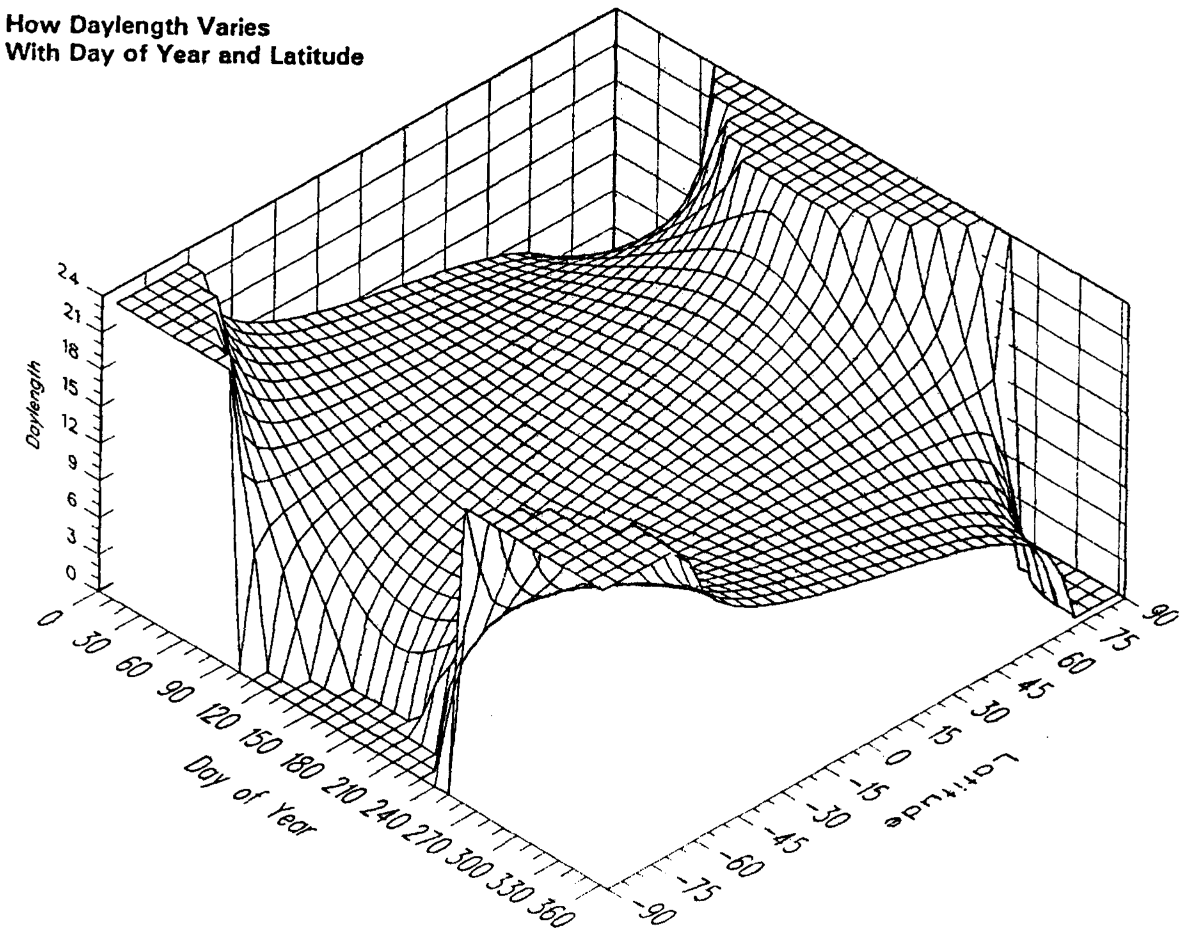


**Figure 3.** Variation in daylength (in hrs) with day of the year (in Julian Days) and latitude (in degrees). Degrees of latitude in the northern hemisphere assigned positive values; degrees of latitude in the southern hemisphere assigned negative values. The steeper the slope to the 3-D plot of daylengths, the greater the accuracy of latitude determinations based upon daylength. Note that position accuracy is better at higher latitudes than lower ones with the least near the equator. Taken from Hill (1991).

The geolocating tags determine latitude by sensing two environmental properties, light and temperature. Daylength, or the time between sunrise and sunset, changes with distance along a meridian on the earth's surface, and thus is an indicator of latitude. The value for length of day can be used with algorithms incorporating the above formulas to calculate latitude. The accuracy of the latitudinal coordinate for a geolocation is proportional to the change in daylength per unit distance in a north-south direction. Daylength varies little near the equator, resulting in little accuracy to the tag's positions there. This is apparent from the absence of any slope to the center of the surface on the 3-D plot of daylength (z-axis) versus day of the year (x-axis) and latitude (y-axis) [Figure 3]. However, farther from equator at intermediate latitudes the variation in daylength is greater, and the positions recorded by a tag here are more accurate. Notice the steep slopes at the edges of the surface of plotted daylengths on the 3-D graph (Figure 3).

A further problem with using daylength as an indicator of latitude is that the former varies with season -- varying mostly during the summer and winter solstices and least during the autumnal and vernal equinoxes. The word "solstice," meaning "sun stands still," refers to times when the sun stops its apparent movement northward or southward motion before staring in an opposite direction. The word "equinox", meaning "equal nights," refers to the time when days and nights are of approximately equal length all over the earth. During the autumnal equinox, the daylength begins to change along a north-south axis only at latitudes higher than 65° with a corresponding increase in positioning accuracy (Figure 4). Notice the extent of the flatness to the surface of plotted lengths of day except around the edges of the plot. The degree of uncertainty is shown for latitude determinations based upon $\pm$ 8 minutes of uncertainty in daylength (Figure 5). Again, the positional error is greatest near the equator around the time of the equinoxes (see the widest portions of the ridges in the surface of the plot). The actual magnitude of the error is not shown as the ridges are truncated at 20 degrees.

Latitudinal error can be reduced in two manners. Firstly, irradiance measurements can be made by the tag at more frequent intervals in order to detect that instant the sun rises above or falls below the horizon with greater temporal resolution. Secondly, the sensor can be modified to better detect sunrise or sunset. One potential method is to cover the sensor with a filter to permit only irradiance of that spectral composition that changes intensity more quickly at dawn or dusk. For instance, yellow-orange light diminishes at dusk more rapidly than blue light. The rapid decline in this band occurs because light from the sun passes through more of the atmosphere when the sun is near the horizon. The ozone in the earth's atmosphere absorbs irrradiance in the 550-600 nm region more quickly than energy in the rest of the spectrum. This phenomenon is known as the Chappuis Effect. Klimley and Mangan (see summary) are currently evaluating the abilities of a photodetector with different narrow and broad band filters to detect sunrise and sunset using an eight-channel underwater radiometer. More accurate detection of sunrise and sunset will lead to a better estimate of daylength, thus resulting in improved latitudinal accuracy.

Tag latitude can also be determined by comparison of the water temperature at a particular depth to a reference field of temperatures. The accuracy of positions based upon long-term mean temperatures

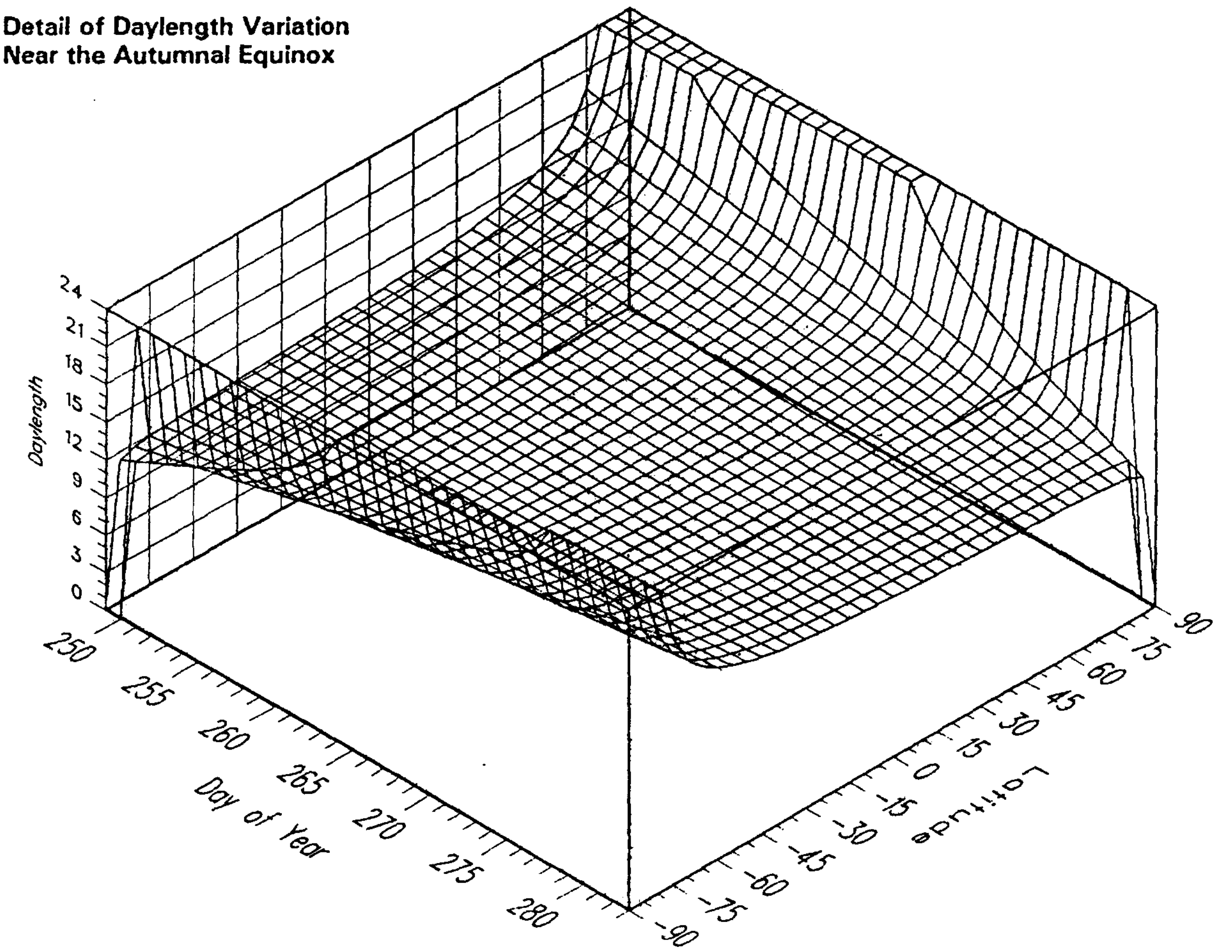


**Figure 4.** Detail of variation of daylength during Julian Days 250-290, those days near the autumnal equinox when daylength changes least with latitude. Note the gradual slope of the 3-D plot of daylengths at all but the highest latitudes, indicative of poor geolocation accuracy. Taken from Hill (1991).

is relatively poor. An improvement is to use as a reference concurrent sea surface water temperatures from AVHRR satellite images, yet less positional accuracy would be expected in coastal areas which often have a temperature structure different from the broad-scale pattern in the open ocean.

Archival tags are now a reality! Data were presented at the workshop from both simple data logging and geol-

**Range of Uncertainty in Latitude Determination**
**Based on ±8 Minutes of Uncertainty in Daylength**
**(truncated to 20 degrees)**

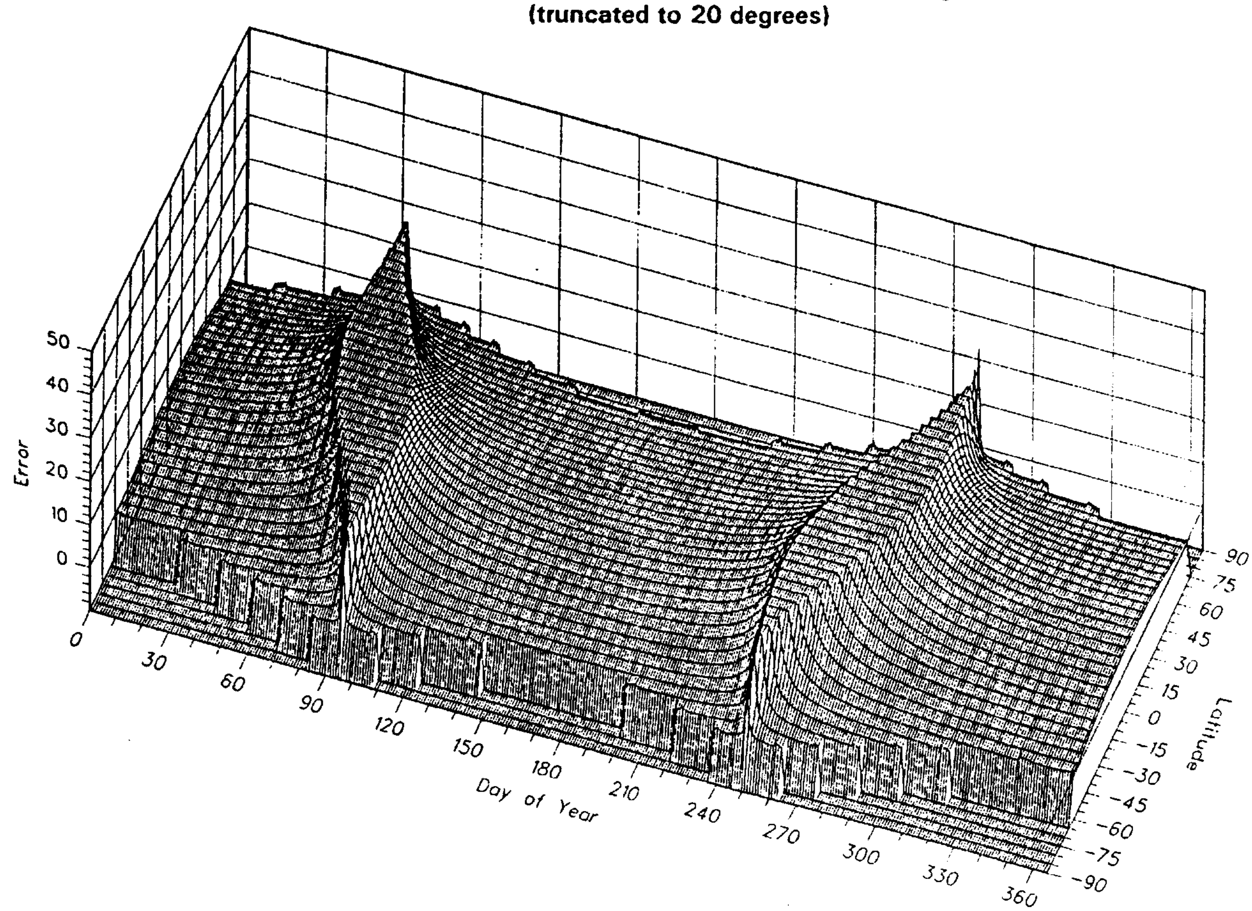


**Figure 5.** Error in latitude determinations based on ± 8 minutes of uncertainty in daylength. Error given in degrees of latitude with 1 degree = 60 nautical miles = 111 km. The error peaks are truncated at 20 degrees. Again, note that the error is greatest at low latitudes around the autumnal and vernal equinoxes. This error can be reduced substantially reducing the length of the intervals at which irradiance is measured from the 8 minute period. Taken from Hill (1991).

ocating archival tags. Arnold deployed 50 data logging tags in the southern North Sea in December 1993 on plaice; a further 40 tags were released in March 1994. Nine tags have so far been returned from the first release and two from the second, producing 462 days data. He presented several long-term records of the vertical excursions of plaice during extensive migratory movements in the North Sea.

Gunn *et al.* deployed 180 geolocating archival tags on southern bluefin tuna (≤25 kg) in South Australia. He showed a record of the vertical excursions of one of these tagged tunas. Of particular interest, was his comparison of tag-determined positions of tuna enclosed in a cage to positions obtained independently as the cage was towed at the sea surface. Although the longitudinal coordinates of these positions were quite accurate, the latitudinal coordinates were considerably less so. Ekstrom and Fralich described the design and operation of the Northwest Marine Technology geolocating archival tag. They demonstrated operating system software during a poster session at the meeting.

**Recommendations for Improvement**

Although archival tags are now available, we believe that improvements in their design will be necessary before they gain widespread use. Firstly, the latitudinal accuracy must be increased if these tags are to be used with fishes other than the most highly migratory species, particularly those species that frequent tropical waters. Daylength and temperature are relatively poor indicators of latitude. Gunn lamented that only two, three, or even four degrees of positional accuracy (=120-240 nautical miles [220-444 km]) is possible using daylength to determine latitude.

We have compiled fisheries data from several sources that can be used to evaluate the feasibility of using archival tags in their present state of development with different migratory species of fish (see Table 1). Firstly, we have obtained estimates of the extent of these migrations from tag-recapture data. There is a bias to underestimate migratory distance using this method. A tagged fish can be caught at only one point along its extensive path across the ocean -- the likelihood of this single point being the most distant point moved from the point of origin is very low. For that reason, we provide two estimators of migratory distance: 1) the mean of the five longest tag-recapture distances and 2) the maximum tag-recapture distance. Secondly, we give the geographic coordinates for the longest movement and a latitude-longitude ratio between that distance moved along a north-south axis to the distance traveled along an east-west axis. This information is useful in evaluating the tag's ability to track the movements of a particular species with minimal error. As an obstacle for the use of the tag, we chose a latitudinal error of 444 km based upon the comments of Gunn during the round-table discussion. Gunn's remarks were based upon preliminary studies of tag accuracy with southern bluefin tunas in Australia. For instance, the 444 km error is only 4.2 % of the mean distance between tag and recapture of 10,383 km for the bluefin tuna (*Thunnus thynnus*), but is 31.1% of the distance of 1,428 km for the blacktip shark (*Carcharhinus limbatus*). We have judged latitudinal accuracy to be a problem if the upper error limit was greater than 10% of the mean of the five longest distances between tag and release for that species, although this criterion may change with additional information. Thus, a "no" occurs under the column of "Lat. Error" under "Obstacles to Use of Archival Tag" for the bluefin and a "yes"

Table 1. Factors to be considered in evaluating the usefulness of using archival tags with particular species of highly migratory fish. For each species the following information is given: 1) mean of the five longest direct distances of travel between tag release and recapture positions, 2) greatest travel distance, 3) latitude and longitude of the tagging and recapture locations for the longest movement, 4) ratio of distance moved along a north-south axis (= lat.) and east-west axis (=long.), 5) number of tags deployed, and 6) percentage of tags returned. Obstacles to the present use of the archival tags are: 1) either lower error limit of 222 km or upper limit of 444 km > 10% of the average of five longest travel distances (see below), 2) the percentage of recapture < 4%, and 3) external attachment necessary. In regard to error, the lower limit was used when the initial and final positions were at latitudes > 50°. The tag-recapture data for salmonids are for the northeastern Pacific (from Kate Myers, University of Washington, Seattle), the data on billfish and sharks for the eastern Atlantic (from Jack Casey and Nancy Kohler, National Marine Fisheries Service, Narragansett and Eric Prince, National Marine Fisheries Service, Miami).

| Common Name (Species) | Migratory Distance | | | | | | | Tag | | Obstacles to Use to Archival Tag | | | | Useful in Present |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean (km) | Max. (km) | Release Latitude | Release Longitude | Recapture Latitude | Recapture Longitude | Lat. / Long. | Rel. (N) | Recap. (%) | Recap. <4% | Lat. Error= 222-444 km | Ext. Attach. ≤25 kg | Needed >25 kg | |
| **OSTEICHTHYES (BONY FISHES)** | | | | | | | | | | | | | | |
| **Salmonidae** | | | | | | | | | | | | | | |
| Chinook (*Oncorhynchus tshawytscha*) | 3,514 | 4,557 | 51°29'N | 176°34'W | 44°30'N | 114°14'W | 0.12 | 513 | 0.39 | Yes | Yes | No | Maybe | No |
| Chum (*O. keta*) | 5,386 | 5,595 | 50°00'N | 140°00'W | 43°00'N | 144°15'E | 0.17 | 20,627 | 0.96 | Yes | No | No | No | No |
| Coho (*O. kisutch*) | 3,356 | 4,762 | 46°59'N | 123°49'W | 43°36'N | 173°47'E | 0.07 | 3,470 | 1.10 | Yes | No | No | No | No |
| Pink (*O. gorbuscha*) | 2,631 | 2,821 | 47°00'N | 136°50'W | 63°50'N | 171°36'W | 0.87 | 10,584 | 0.60 | Yes | Yes | No | No | No |
| Sockeye (*O. nerka*) | 3,711 | 4,224 | 47°31'N | 177°32'E | 48°20'N | 124°20'W | 0.04 | 7,830 | 1.38 | Yes | No | No | No | No |
| Steelhead (*O. mykiss*) | 5,531 | 5,905 | 46°09'N | 115°58'W | 41°34'N | 167°35'E | 0.07 | 310 | 2.59 | Yes | No | No | No | Maybe |
| **Scombridae** | | | | | | | | | | | | | | |
| Albacore (*Thunnus alalunga*) | 503 | 1,438 | 33°42'N | 16°20'W | 38°40'N | 28°00'W | 0.67 | 737 | 1.76 | Yes | Yes | No | No | No |
| Bigeye (*T. obesus*) | 759 | 1,991 | 47°30'N | 39°30'W | 43°40'N | 57°00'W | 0.54 | 959 | 0.31 | Yes | Yes | No | Yes | No |
| Bluefin (*T. thynnus*) | 10,383 | 11,421 | 25°30'N | 79°18'W | 68°38'N | 14°00'E | 0.78 | 30,134 | 12.11 | No | No | No | Yes | Yes |
| Yellowfin (*T. albacares*) | 8,695 | 9,424 | 37°00'N | 75°00'W | 03°00'S | 00°13'W | 0.50 | 6,083 | 3.17 | Yes | No | No | Yes | Maybe |
| **Xiphiidae** | | | | | | | | | | | | | | |
| Swordfish (*Xiphias gladius*) | 3,789 | 4,609 | 27°55'N | 76°92'W | 47°35'N | 40°23'W | 0.75 | 6,671 | 2.73 | Yes | Yes | Maybe | Yes | No |
| **Istiorphoridae**[a] | | | | | | | | | | | | | | |
| Blue marlin (*Makaira nigricans*) | 8,801 | 15,941 | 38°20'N | 73°30'W | 19°00'S | 58°00'E | 0.69 | 17,993 | 0.55 | Yes | No | Yes | Yes | No |
| Sailfish (*Istiophorus platypterus*) | 3,493 | 4,003 | 35°50'N | 75°30'W | 08°07'N | 52°39'W | 0.95 | 57,820 | 1.60 | Yes | Yes | Maybe | Yes | No |
| Spearfish (*Tetrapturus angustirostris*) | | | | | | | | 251 | 0 | Yes | Yes | Maybe | Yes | No |
| White marlin (*T. albidus*) | 4,965 | 6,541 | 18°40'N | 64°50'W | 34°00'N | 08°00'W | 0.31 | 27,053 | 1.62 | Yes | No | Maybe | Yes | No |
| **ELASMOBRANCHII**[a] **(SHARKS)** | | | | | | | | | | | | | | |
| **Alopiidae** | | | | | | | | | | | | | | |
| Thresher (*Alopius superciliosus*) | 1,380 | 2,767 | 39°33'N | 68°13'W | 27°30'N | 84°50'W | 1.00 | 57 | 3.5 | Yes | Yes | No | No | No |
| **Lamnidae** | | | | | | | | | | | | | | |
| Shortfin Mako (*Isurus oxyrinchus*) | 3,536 | 4,542 | 40°09'N | 68°23'W | 38°38'N | 14°41'W | 0.03 | 2,459 | 9.4 | No | No | No | No | Yes |
| **Carcharhinidae** | | | | | | | | | | | | | | |
| Blacktip (*Carcharhinus limbatus*) | 1,428 | 2,146 | 35°54'N | 74°42'W | 27°40'N | 84°50'W | 0.98 | 2,005 | 4.5 | No | Yes | No | No | No |
| Blue (*Prionace glauca*) | 6,265 | 6,927 | 40°22'N | 72°00'W | 05°23'S | 25°48'W | 0.78 | 36,290 | 3.8 | Yes | No | No | No | Maybe |
| Dusky (*C. obscurus*) | 3,800 | 4,911 | 41°03'N | 71°20'W | 22°15'N | 97°25'W | 0.77 | 6,067 | 2.2 | Yes | Yes | No | No | No |
| Oceanic Whitetip (*C. longimanus*) | | 2,863 | 39°27'N | 72°14'W | 20°02'N | 79°38'W | 3.37 | 525 | 0.8 | Yes | Yes | No | No | No |
| Sandbar (*C. plumbeus*) | 3,692 | 3,761 | 40°56'N | 71°43'W | 22°50'N | 97°20'W | 0.81 | 15,636 | 5.0 | No | Yes | No | No | Maybe |
| Tiger (*Galeocerdo cuvieri*) | 2,502 | 3,675 | 39°48'N | 72°40'W | 10°10'N | 82°30'W | 3.40 | 4,219 | 9.6 | No | Yes | No | No | Maybe |

[a]Sharks weighing up to 100 kg are regularly handled before being held in captivity, and it is anticipated that these species could be fitted with internal archival tags.

is under the same column for the blacktip (Table 1).

However, there are considerations other than just the distance moved by the fish. The latitudinal error is less of an obstacle to tracking species that move mainly east-west rather than north south or have a temperate rather than tropical distribution. The archival tag could effectively be used on the shortfin mako shark (*Isurus oxyrinchus*) with a latitude-longitude ratio of 0.03 for its maximum tag-recapture distance of 4,542 km. The ratio indicates that for every 3 km the mako moved along a north-south axis, the shark moved 100 km along an east-west axis. In contrast, the archival tag could not effectively be used with the pelagic whitetip with a latitude/longitude ratio of 3.37 for a maximum separation distance of 2,863 km between tag and recapture. This individual moved 3.37 km along a north-south axis for every 1.00 km along an east-west axis. It is also important to keep in mind that the positional error is smaller at higher latitudes than at lower latitudes. The error is closer to 222 km near the poles and reaches 444 km near the equator. In this respect, daylength is better suited to estimating the latitude for movements of the temperate salmonids than the tropical scombrids, xiphiids, and istiophorids.

A need exists for accurate estimates of error at different times of year and latitudes for the archival tags. Klimley and Mangan are currently conducting measurements with an underwater radiometer of the intensity changes in seven narrow bands and one broad band of irradiance during dawn and dusk on research cruises in the temperate waters off Bodega Bay, semi-tropical waters of San Diego, and tropical waters of Hawaii. The archival tags of CSIRO, Northwest Marine Technologies, Inc., and Wildlife Computers are being deployed with the radiometer to verify and improve the accuracy of prototype tags in detecting the times of sunset and sunrise based upon independent measurements of irradiance.

The tag's ability at determining latitude would be improved greatly by the addition of a sensor of magnetic field intensity. The intensity of the earth's magnetic field changes substantially with latitude (Figure 6). Total geomagnetic field intensity decreases in the Northeast Pacific Ocean from 53,000 nanoTeslas (nT) at 60° N. to 34,000 nT at the equator, a latitudinal magnetic gradient of 316.7 nT per degree. Divide the nautical miles in a degree of latitude (60) by the nanoTeslas per degree (316.7) to arrive at 0.18 nautical miles (per nT). A magnetic sensor with an accuracy of 30 nT (thereby oblivious to the day-night fluctuations in magnetic field) would have an accuracy of 5.4 nautical miles (= 10.0 km). Klimley and Mangan discussed the use of either of two sensors with the above sensitivity, magnetoresistive and magneto-optic, for determining the latitude of fishes. They recommended development of a magneto-optic sensor for the tag. This sensor would not produce a magnetic field itself, and for this reason not interfere with the magnetic sense of fishes.

Determination of an accurate longitude coordinate to a geolocation is considerably less difficult than for latitude. Tests performed by Gunn and his col-

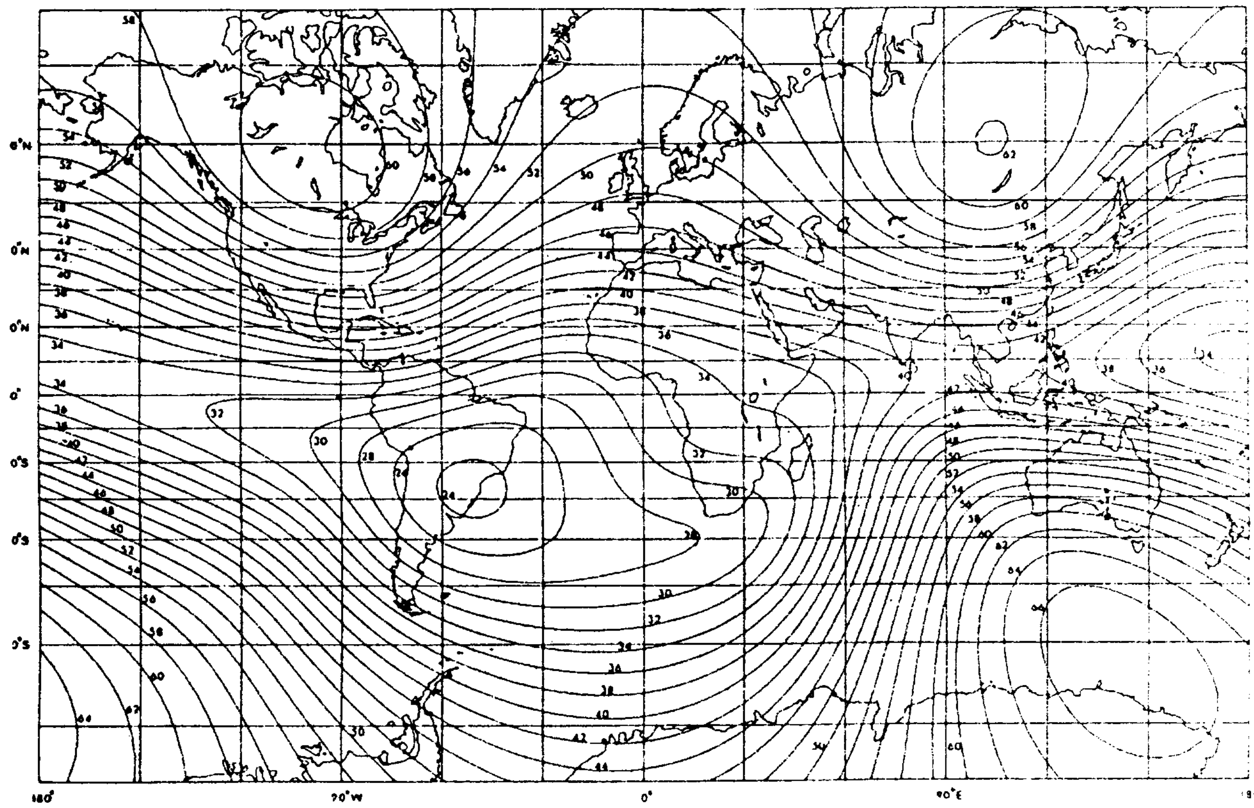

**Figure 6.** Isodynamic contour chart for 1980 showing the variation of total geomagnetic intensity over the earth's surface. Contours are labelled in units of 1000 nanoTeslas. Taken from Merrill and McElhinny (1983).

leagues at CSIRO and Ekstrom and Fralich of Northwest Marine Technologies, Inc., indicate that the longitude coordinates of positions obtained by their tags are fairly accurate. The accuracy of the longitude coordinate depends upon the resolution with which sunrise or sunset can be timed. For instance, the positional accuracy at the equator with a one minute resolution can be determined in the following manner. The amount of rotation to the earth during a day (360°) is divided by the number of minutes in a day (1,440 min) to obtain 0.25 degree of rotation per minute. This value is multiplied by the distance along the equator equivalent to one degree of longitude (60 nautical miles) to obtain a positional error of 15 nautical miles (= 27.8 km). With a temporal resolution of 10 min, the tag's positional error would be 150 nautical miles. Although this may be tolerable with tracks of highly migratory species such as the bluefin tuna, it may preclude the use of the tag with less migratory coastal species or a very tropical species. Therefore, a thorough understanding of the changes in light underwater during twilight is essential to maximize the accuracy of the longitude coordinate. For instance, as mentioned before, an increase in resolution may be achieved by recording energy in specific wavelengths that change more rapidly than broad-band light during twilight.

A second concern of the conference participants was the need to improve the recovery rate of data from the tags. At the present time, all archival tags require that the tagged fish be recaptured in order to retrieve its data. The percentage of tag returns in studies of highly migratory species varies widely (see Table 1). For those species with large numbers of individuals tagged (>10,000), the recapture rates range from only 0.55% of the 17,993 tagged blue marlin to 12.11% of the 30,134 tagged bluefin tuna. The conference participants believed that the use of archival tags would only be practical with species with tag-recapture rates exceeding 4% -- four records would result from every 100 fish tagged. The return rates for five species in Tb. 1 exceed a value of 4%. These species are the: 1) bluefin tuna, 2) tiger shark (*Galeocerdo cuvieri*) [9.6%], 3) shortfin mako shark (9.4%), 4) sandbar shark (*Carcharhinus plumbeus*) [5.0%], and 5) blackfin shark (4.5%). For a species with the threshold return rate, 25 tags at $1,000 each would have to be deployed to obtain one tag return. However, even a single archival tag would provide an extremely valuable series of daily positions for that fish. Kleiber emphasized that one could equate each daily position determined by an archival tag with a recapture location of a conventionally tagged fish. Granted that this is true, an archival tagging program would be no more costly than present conventional tag and recapture programs. However, Brill pointed out the danger inherent in basing management decisions on only a few continuous tracks of a small number of individuals. If these were particularly variable members of a population, the pathways described might be misleading in relation to the majority of members of the population.

How could the recovery or retrieval rate of data be improved? Klimley and Mangan suggested the use of "listening stations" moored at locations to which fish return (Figure 7). An ultrasonic modem, added to the archival tag, could transmit the stored data to a submerged receiver. Its modem would periodically transmit a "chirp" signal that would "wake up" the tag's modem and "instruct" it to transmit data. Upon reception by the submerged receiver, the data would pass up an underwater cable to a buoy at the surface that would either transmit them directly via a packet radio link to a shore station or uplink them to a satellite. These automated monitors could be placed at sites where species congregate such as reefs, fish aggregating devices, seamounts, or small islands (Figure 7). A pilot project to evaluate this concept is presently being conducted in Hawaii where yellowfin tunas are being tagged with individually coded, long-term, ultrasonic tags at three FADs off Kaena Point, Hawaii.

Another method for increasing the rate of recovery of data, mentioned by Block, Klimley, and Nishida, would be to equip the archival tag with a radio transmitter that would uplink data while floating at the surface after releasing from the fish at a preset time. The radio uplink may become a viable data recovery method if Orbital Communications launches its set of 26 ORBCOM satellites into orbits around the earth. These satellites are being designed so that as one satellites drops below the horizon another satellite will rise above the horizon. In this way a satellite will always be "in view" of the transmitter. Each satellite will have a "footprint" diameter of 4600 km from which it can receive a signal. Data will be able to be transmitted to these satellites at a rate of 2400 bps on 10 kHz wide channels in the 148 and 150 MHz band. The data in the satellites will be downlinked at 56 Kbps on a 50 KHz wide channel in the 137 MHz band. The signal, received by one of several Earth Gateway Stations, will be transmitted via microwave or cable to a Network Control Center. Customers will be able to either obtain data via telephone modem or directly receive the signal at a remote terminal. The latter will be capable of localizing the "pop-up" transmitters based upon the Doppler shift of their signals -- thus making possible the recovery of data from expensive tags.

The third concern of conference participants was fish collection, handling, and tag attachment problems. Block emphasized that the archival tags would have to be attached externally to the larger tunas and billfishes. Although Gunn *et al.* described internal placement of archival tags on southern bluefin tuna weighing less than 25 kg during their scientific presentation, in the round-table discussion he informed the group that experiments were currently being carried out on an external method of attachment. Tunas weighing more than 25 kg present a major obstacle to handling and collection. These fishes are just too powerful to subdue for internal tag placement without anesthesia, and applying it in the open ocean is difficult. For example, billfishes weighing more than 25 kg are very dangerous when near or on a boat because they slash their upper bill back and forth, thus making internal implantation hazardous. In addition, handling large highly migratory species also runs the risk of harming the animal, particularly if anesthesia is not used. The placement of archival tags in sharks is not anticipated to be an obstacle because these species are regularly handled while in captivity. The feasibility of either internal or external placement of tags is evaluated with regard to size and species in Table 1.

Prince mentioned the need to test the methods of archival tag attachment, as well as fish handling and collection so that trauma to tagged fishes is minimized. An external attachment method using an anchoring mechanism that does not require that the fish be taken out of the

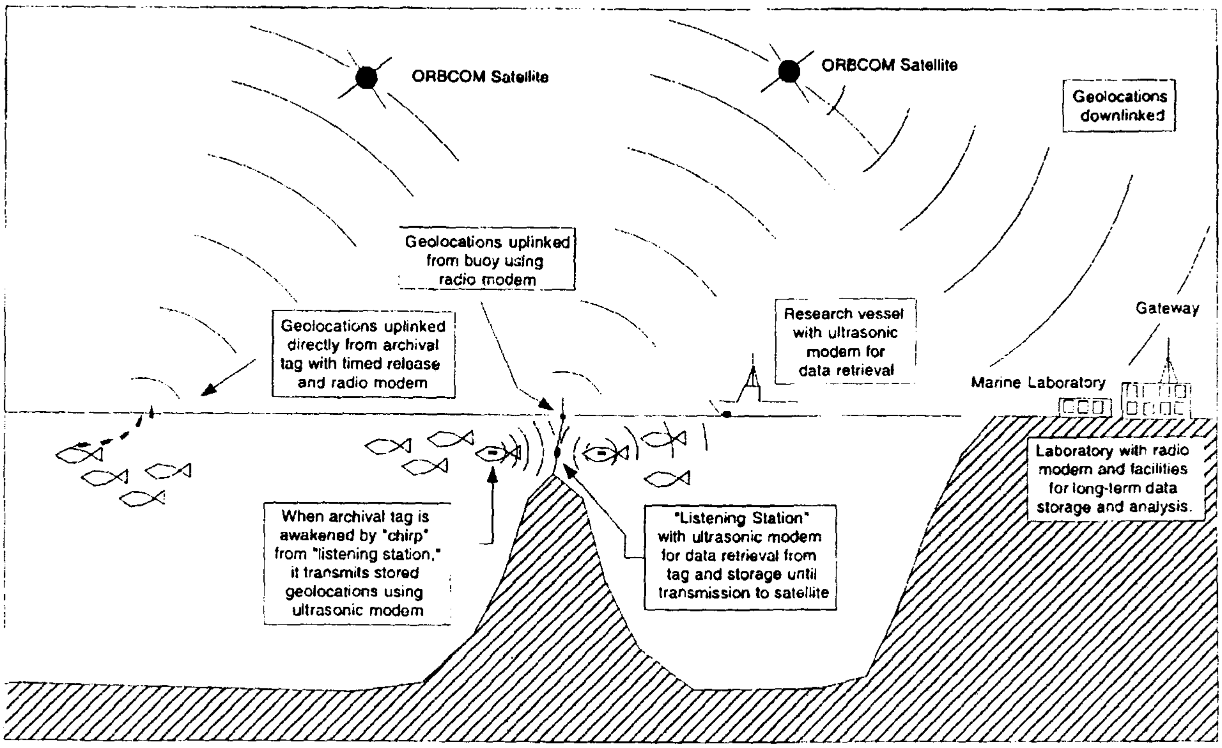


**Figure 7.** A future system for monitoring the global scale movements of marine animals. An archival tag on a fish will store daily positions based upon measurements of irradiance, geomagnetic field intensity, and temperature. Upon receiving an interrogation "chirp" sent from a "listening station," the tag will transmit its contents via an ultrasonic frequency-shifted signal to the listening station. The data will then be uplinked to a satillite via an radio signal transmitted from a buoy and downlinked to Gateway Station on land. These listening stations can be situated at locations at which fish aggregate such as islands, seamounts, escarpments, reefs, and Fish Aggregation Devices (FADs). In the future, the archival tags may even detach from the fish at a preset time, float to the surface, and uplink their information with a satellite.

water, or anesthetized, was considered the best mode of attachment by the group. One approach that should be investigated is to miniaturize the archival tag and use a harpoon to place the tag in the dorsal musculature of larger fish. However, any method employed must not only be easy to implement but also provide an attachment that must last the anticipated lifetime of the tag.

## Performance Characteristics

| *Performance Descriptors* | *Present* | *Future* |
|---|---|---|
| (1) Migratory route over time (see summary of Gunn *et al.*) | Yes | Yes |
| (2) Longitudinal accuracy < 1 degree | Maybe | Yes |
| (3) Latitudinal accuracy < 1 degree (see Klimley & Mangan, A) | No | Yes |
| (4) Depth preferenda (see Arnold and Gunn *et al.*) | Yes | Yes |
| (5) Thermal preferenda (see Arnold and Gunn *et al.*) | Yes | Yes |
| (6) Tidal preferenda (see Arnold) | Yes | Yes |
| (7) Data recovered via listening stations (see Klimley & Mangan, B) | No | Yes |
| (8) Data recovered via satellite uplink | No | Maybe |

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Highly Migratory Species Management Division (F/CM4)
1315 East West Hwy.
Silver Spring, Maryland 20910
Tel: 301-713-2347 Fax: 301-713-1035

## Appendix A

(1) **Navigational algorithms for calculating sunrise and sunset** (taken from U.S. Naval Observatory Nautical Almanac Office. 1990. Almanac for Computers 1990. U.S. Naval Observatory, Washington, D.C.)

## Appendix B

*(Specifications for Archival Tags)*

(1) **Ultra-miniature Recorders, MDS, Micro Data-recorder System:** Alec Electronics Co., Ltd., 7-11 Ohishi-Kitamachi, Nada-ku, Kobe, Japan, 657, Tel: 078-802-2106, Fax: 078-802-1865.

(2) **CSIRO Smart Tag:** Miron Nicolau, Zelcon Technic Pty. Ltd., P.O. Box 149, Tasmania, Australia 7010, Tel: 61-02-718-120, Fax: 61-02-718-182, ana@cor.med.utas.edu.au.

(3) **Data Storage Tags:** Dr. Julian Metcalfe (Project Scientist), Directorate of Fisheries Research, Pakefield Road, Lowestoft NR33 OHT, U.K., Tel: 0502-562244, Fax: 0502-513865.

(4) **Northwest Marine Techology Archival Tag:** Northwest Marine Techology, Inc., P.O. Box 427, Ben Nevis Road, Shaw Island, Washington 98286, U.S.A., Tel: 206-468-3375, Fax: 206-468-3844.

(5) **Minilog - Temperature & Depth Logger:** VEMCO Limited, 3895 Shad Bay, Nova Scotia, Canada, B3L-4J4, Tel: 902-852-3047, Fax: 902-852-4000.

(6) **Mk3+, MK3e, and MK5 Time-Depth Recorders with Geolocating Option:** Roger D. Hill & Suzanne E. Hill, Wildlife Computers, 20630 N.E. 150th St., Woodinville, WA 98072-7641, Tel: 206-881-3048, Fax: 206-881-3405.

# Appendix A

**Sunrise, Sunset and Twilight**

For location between latitudes 65° North and 65° South, the following algorithm provides times of sunrise, sunset and twilight to an accuracy of $\pm 2^m$, for any date in the latter half of the twentieth century. Because the phenomena depend on local meteorological conditions, attempts to attain higher accuracy are seldom justified. Although the algorithm can be used at higher latitudes, its accuracy deteriorates near dates on which the Sun remains above or below the horizon for more than twenty-four hours.

Notation:

- $\varphi$: latitude of observer (north is positive; south is negative)
- $\lambda$: longitude of observer (east is positive; west is negative)
- $M$: Sun's mean anomaly
- $L$: Sun's true longitude
- $RA$: Sun's right ascension
- $\delta$: Sun's declination
- $H$: Sun's local hour angle
- $z$: Sun's zenith distance at rise, set or twilight*
- $t$: approximate time of phenomenon in days since 0 January, $0^h$ UT
- $T$: local mean time of phenomenon
- $UT$: universal time of phenomenon

*The proper value of $z$ should be chosen from the following:

| | $z$ | $\cos z$ |
|---|---|---|
| Sunrise and Sunset | 90°50′ | −0.01454 |
| Civil Twilight | 96° | −0.10453 |
| Nautical Twilight | 102° | −0.20791 |
| Astronomical Twilight | 108° | −0.30902 |

Formulas:

(1) $M = 0\overset{\circ}{.}985600\,t - 3\overset{\circ}{.}289$

(2) $L = M + 1\overset{\circ}{.}916 \sin M + 0\overset{\circ}{.}020 \sin 2M + 282\overset{\circ}{.}634$

(3) $\tan RA = 0.91746 \tan L$

(4) $\sin\delta = 0.39782 \sin L$

(5) $x = \cos H = (\cos z - \sin\delta \sin\varphi)/(\cos\delta \cos\varphi)$

(6) $T = H + RA - 0\overset{h}{.}065710\,t - 6\overset{h}{.}622$

(7) $UT = T - \lambda$

Procedure:

1. With an initial value of $t$, compute $M$ from eq. (1) and then $L$ from eq. (2). If a morning phenomenon (sunrise or the beginning of morning twilight) is being computed, construct an initial value of $t$ from the formula
$$t = N + (6^h - \lambda)/24,$$
where $N$ is the day of the year (see the calendar on pages A2–A3 or the formulas on page B1) and $\lambda$ is the observer's longitude expressed in hours. If an evening phenomenon is being computed, use
$$t = N + (18^h - \lambda)/24.$$
2. Solve eq. (3) for $RA$, noting that $RA$ is in the same quadrant as $L$. Transform $RA$ to hours for later use in eq. (6).
3. Solve eq. (4) for $\sin\delta$, which appears in eq. (5); $\cos\delta$, which also is required in eq. (5), should be determined from $\sin\delta$. While $\sin\delta$ may be positive or negative, $\cos\delta$ is always positive.
4. Solve eq. (5) for $H$. Since computers and calculators normally give the arccosine in the range 0°–180°, the correct quadrant for $H$ can be selected according to the following rules:
   rising phenomena: $H = 360° - \arccos x$;
   setting phenomena: $H = \arccos x$.
   In other words, for rising phenomena $H$ must be either in quadrant 3 or 4 (depending on the sign of $\cos H$), whereas $H$ must be either in quadrant 1 or 2 for setting phenomena. Convert $H$ from degrees to hours for use in eq. (6).
5. Compute $T$ from eq. (6), recalling that $H$ and $RA$ must be expressed in hours. If $T$ is negative or greater than $24^h$, it should be converted to the range $0^h$–$24^h$ by adding or subtracting multiples of $24^h$.
6. Compute $UT$ from eq. (7), where $\lambda$ must be expressed in hours. $UT$ is an approximation to the time of the desired rising or setting phenomenon, referred to the Greenwich meridian. If $UT$ is greater than $24^h$, the phenomenon occurs on the following day, Greenwich time. If $UT$ is negative, the phenomenon occurs on the previous day, Greenwich time.

To ensure that precision is not lost during the computations, $t$ should be carried to three decimal places. Angles should be expressed to three decimals of a degree and, upon conversion, to three decimals of an hour. Five significant digits should be carried for the trigonometric functions.

Under certain conditions, eq. (5) will yield a value of $|\cos H| > 1$, indicating the absence of the phenomenon on that day. At far northern latitudes, for example, there is continuous illumination during certain summer days and continuous darkness during winter days.

Example: Compute the time of sunrise on 25 June at Wayne, New Jersey.

Latitude: $40\overset{\circ}{.}9$ North $\quad \varphi = +40\overset{\circ}{.}9 \quad \sin\varphi = +0.65474 \quad \cos\varphi = +0.75585$

Longitude: $74\overset{\circ}{.}3$ West $\quad \lambda = -74\overset{\circ}{.}3/15 = -4\overset{h}{.}953$

For sunrise: $z = 90°50'$ $\quad \cos z = -0.01454$

$t = 176^d + (6^h + 4\overset{h}{.}953)/24 = 176\overset{d}{.}456$

$M = 0\overset{\circ}{.}985600(176\overset{d}{.}456) - 3\overset{\circ}{.}289 = 170\overset{\circ}{.}626$

$L = 170\overset{\circ}{.}626 + 1\overset{\circ}{.}916(0.16288) + 0\overset{\circ}{.}020(-0.32141) + 282\overset{\circ}{.}634$

$\quad = 453\overset{\circ}{.}566 = 93\overset{\circ}{.}566$

$\tan RA = 0.91746(-16.046) = -14.722$

Since $L$ is in quadrant 2, so is $RA$: $\quad RA = 93\overset{\circ}{.}886/15 = 6\overset{h}{.}259$

$\sin\delta = 0.39782(0.99806) = 0.39705$

$\cos\delta = 0.91780$

$x = \cos H = (-0.01454 - (0.39705)(0.65474))/((0.91780)(0.75585))$

$\quad = -0.39570 \qquad \arccos x = 113\overset{\circ}{.}310$

Since sunrise is being computed, $H = 360° - 113\overset{\circ}{.}310 = 246\overset{\circ}{.}690$

$H = 246\overset{\circ}{.}690/15 = 16\overset{h}{.}446$

$T = 16\overset{h}{.}446 + 6\overset{h}{.}259 - 0\overset{h}{.}065710(176\overset{d}{.}456) - 6\overset{h}{.}622 = 4\overset{h}{.}488$

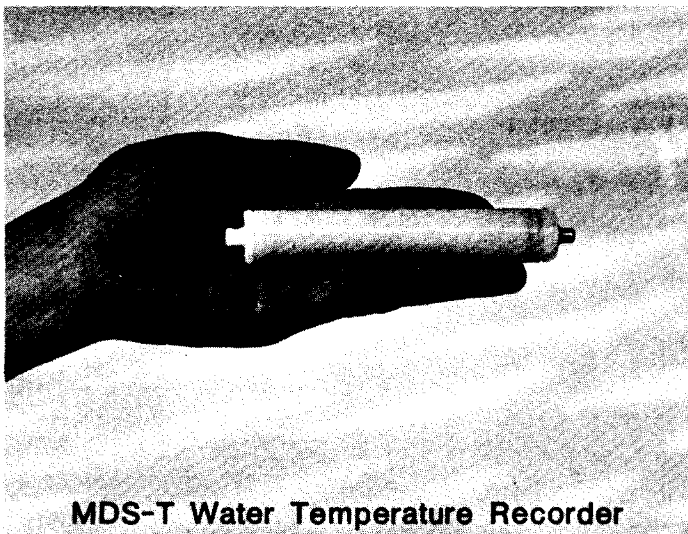
$UT = 4\overset{h}{.}488 + 4\overset{h}{.}953 = 9\overset{h}{.}441$

Sunrise occurs at $9^h26^m$ UT $= 5^h26^m$ EDT

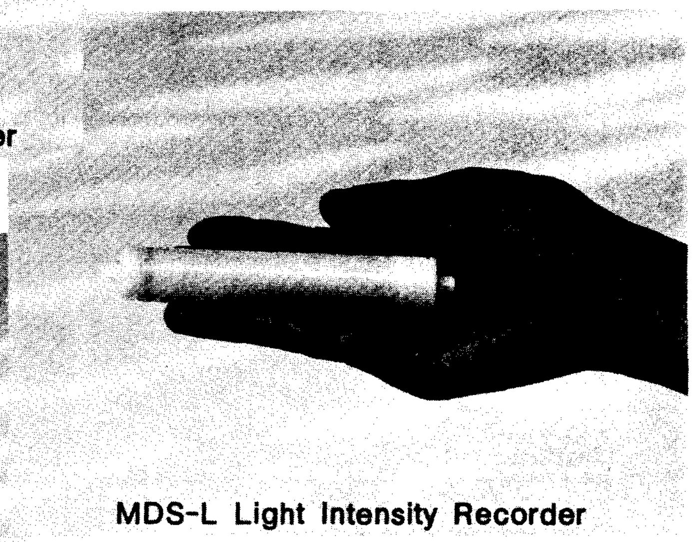
ALEC ELECTRONICS

# ULTRA-MINIATURE RECORDERS

# MDS



MDS-T Water Temperature Recorder



MDS-L Light Intensity Recorder

MDS-D Water Depth Reco

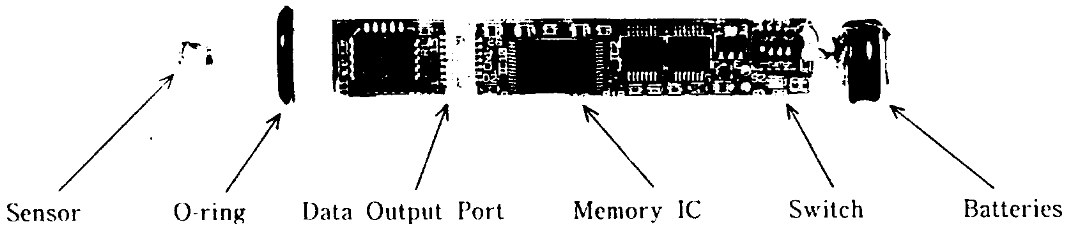
ALEC ELECTRONICS CO.,LTD.

7-11 Ohishi-Kitamachi, Nada-ku
Kobe, Japan

The MDS Micro Data-recorder System is a series of ultra-miniature recorders for water temperature, pressure (depth) and light intensity measurements. The pressure case of these units, designed for 500 meter depth, is 18 mm in diameter and 109 mm in length. It contains the Sensor, Sensor Amplifier, A/D Converter, Clock, Memory IC, Batteries, plus a data output connector and function switch.

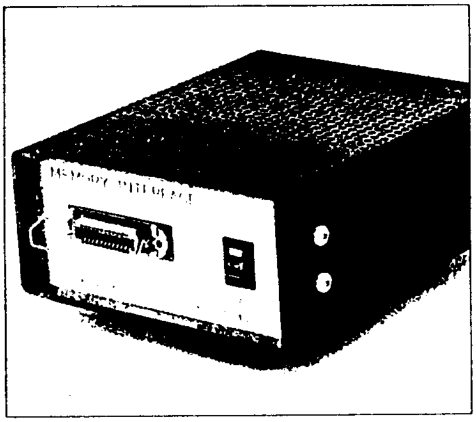
The Recorder has a memory capacity of 32k bytes which provides enough memory for 440 days of continuous measurement when using a 20 min interval. Using the interface unit and software available from Alec Electronics, recorded data can be transferred to a PC for compiling and further analysis.

Developed for underwater studies of various mammals and fish, these recorder's unique size and features find use in a variety of other field applications.




Specifications common to MDS Series

| | |
|---|---|
| Memory Capacity | 32000data (32K-bytes) ( 1 data = 8 bits) |
| Sampling Interval | 1 sec, 1, 10, 20 minute (Selectable by a Dip Switch) |
| Power Source | Lithium Batteries ( 2 ea of CR1220P, 35mAh) |
| Housing Material | Polyester Resin (White) |
| Pressure Capacity | 500 meters |



Specifications

| Model | MDS-T | MDS-L | MDS-D |
|---|---|---|---|
| Parameter | Water Temperature | Under-water Light Intensity | Water Depth |
| Sensor Type | Thermistor | Photo Diode | Semi-Conductive |
| Measuring Range | 0℃～30℃ | 0～1200μm/m²·sec | 0～200m/0～500m |
| Accuracy | ±0.15℃ | ±0.4% FS | ±1m/±2m |
| Response Time | 2 seconds | 2 seconds | 1 second |
| Dimensions | φ18×109mm | φ18×109mm | φ18×127mm |
| Weight (in air/in water) | 28.4/3.5 g | 28.4/3.5 g | 33.6/5.0 g |

**ALEC ELECTRONICS CO.,LTD.**

7-11 OHISHI-KITAMACHI, NADA-KU, KOBE, JAPAN, 657

TEL:078-802-2106

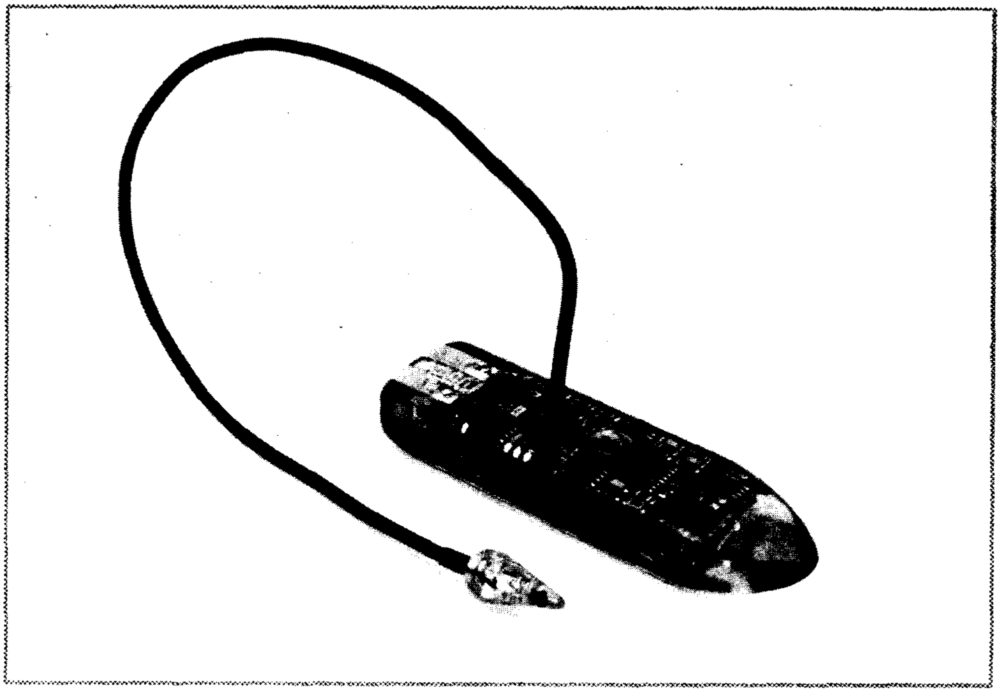
FAX:078-802-1865

Appendix (2)

# CSIRO SMART TAGS

Advanced surface mount technology is employed in these miniature data loggers that have ben specifically designed for use on small marine mammals and fishes.

The tags are currently being used on tunas, whale sharks and seals, and a range of terrestrial mammals to study behaviour, movement and physiology. Software to estimate geolocation and provide graphical representation of data is also available.



**Technical details:**

| | | |
|---|---|---|
| Size | 55 x 24 x 12 mm | |
| Weight (in air) | 25 grams | |
| Memory capacity | 512 K (1 Mbyte with Flash Memory; Gunn, pers Comm.) | |
| Sensors* | Light, depth, internal and external temperatures | |
| Logging life** | 4 — 5 years | |
| Data retention | >20 years | |
| Cost (US$) | Tags | $1000 |
| | Software | upon application |

*Other sensors available.
**Tags are re-useable within this time.

**Contacts on technical details and availability:**
Miron Nicolau, Zelcon Technic Pty Ltd.
PO Box 149, Glenorchy, Tasmania, Australia 7010
Fax – 61 02 718 182 Phone – 61 02 718 120
Email – <ana@cor.med.utas.edu.au>

**Scientific details and applications:**
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PO Box 1538, Hobart, Tasmania, Australia 7001
Fax – 61 02 325 000 Phone – 61 02 325 222
Email – <gunn@aqueous.ml.csiro.au>

CSIRO
ION OF FISHERIES

Directorate of Fisheries Research

# Data Storage Tags

## for use in studies of fish migration

### Preamble

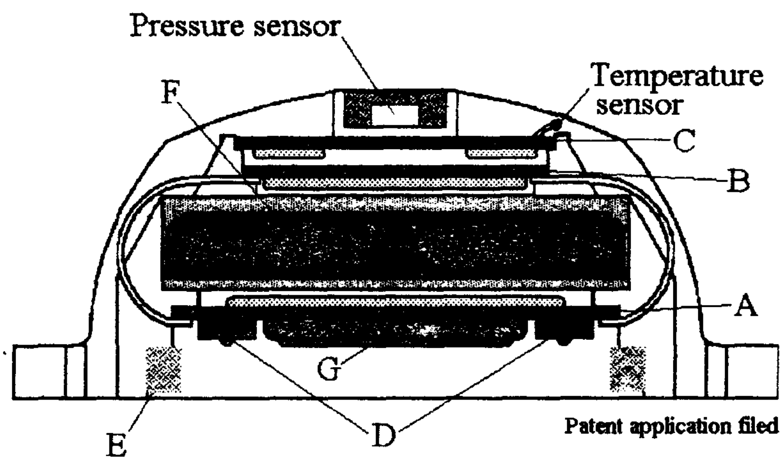
For almost 25 years, MAFF electronics engineers at the Fisheries Laboratory in Lowestoft have been designing and building various miniature electronic tags for acoustic or radio tracking of fish. By and large, these tags have been for our own biological research programmes into fish movements and behaviour, although some of our radio tags are now made under licence by an outside contractor and are available commercially.

In an attempt to be less reliant on expensive research vessels, and in order to be able to perform controlled, replicated experiments in the open sea, we have more recently developed an electronic tag which **records** and **stores** environmental and behavioural data. Like conventional fish tags, these data storage tags are designed to be returned via the commercial fishery.

### Summary specification

The tag has three electronic circuit boards: a logger board containing a programmable micro controller (**A**); a mass data store with 1 Mbit of memory (**B**); and an analogue sensor board (**C**). The tag has eight sensor channels, although only two are used in the tag at present to measure pressure and temperature. This arrangement offers the flexibility to design a family of analogue boards with different sensors tailored to meet different requirements. The tag is totally encapsulated in a light epoxy resin to keep weight to a minimum.

Programming and data retrieval are carried out using a tag reading unit and "user-friendly" PC *Tagtalk* software with pull-down menus and on-screen help. Communication is via a two-way serial RS232 infra-red optical link (**D**) operating through the tag casing. Power for communication does not depend on the tag batteries but is provided externally from an inductively coupled coil (**E**).




Instructions for data logging are programmed into a **sample table** allowing each sensor channel to be sampled independently

Continued overpage

 Further information can be obtained from Dr Julian Metcalfe ( Project Scientist), Directorate of Fisheries Research, Pakefield Road, LOWESTOFT NR33 0HT, UK. Tel: 0502-562244, Fax: 0502-513865.

with any sequence of sampling protocols. For example, one channel can be set to take no samples for 20 days, then take 100 samples at hourly intervals and then take 500 samples at 3-hourly intervals, while another channel takes 1 sample every 12 hours over the same period.

The present tag records pressure to give depth to 100m with a resolution of 0.2 m and temperature in the range -4 to 23°C ± 0.03°C. It is a domed device, 46 mm (dia) x 22 mm (max. height) weighing about 55 g in air and 23 g in sea water. The tag can record data for up to about 9 months and, with 1 Mbit (128k by 8 bit) of memory, store at least 32 000 data samples. Calibration data for each sensor are stored in the tag so that, on return, the user can quickly download and translate the data into engineering units for display, for example, in a spreadsheet. When the tag has completed its sampling regime, filled its memory, or exhausted the main battery (F), it automatically switches to a disabled state and uses its backup battery (G), to retain the recorded data for at least 5 years.

## Future development

Recent reductions in the size of memory chips should allow us to expand the memory to 2 Mbit shortly, and our design engineers are continually striving to incorporate new developments in silicon die technology to reduce the size, weight and power requirements of the tag. We are also designing a cylindrical version of the tag, which will be about 20 mm (dia) x 74 mm, and development of a solid state compass sensor is well under way. Development of sensors for water speed, tilt angle, and light intensity are also planned.

Dr Julian Metcalfe
Project Scientist
DFR, Lowestoft
January 1994

Appendix

# Northwest Marine Technology, Inc.

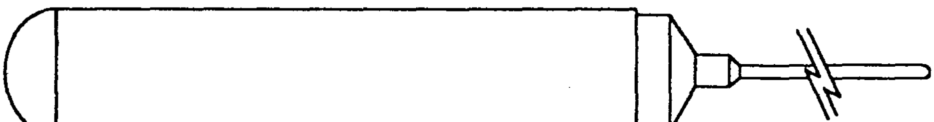
Pioneering solutions for the problems of aquatic resource management

18 May, 1994

## Northwest Marine Technology Archival Tag

The NMT Archival Tag is primarily intended to be attached to or implanted in a large pelagic fish such as a Tuna to determine and record its position and key environmental variables every day for a period of years. When recovered and interrogated it will yield that position information along with statistical summaries of all data measured and a detailed time series record of a portion of the mission.

The tag is housed in a stainless-steel cylinder 16 mm in diameter and 100 mm long. A thin, flexible measurement stalk 2 mm in diameter is attached to one end, and when the tag is implanted the stalk extends through the skin of the animal to trail in the water. The extreme 30mm of the stalk houses the light sensor and the sensor for external temperature. The pressure sensor and the sensor for internal temperature are in the body of the tag.



The tag uses times of sunrise and sunset to determine longitude and the sea temperatures at standard depths to determine latitude. This approach is presented in NMFS technical memorandum NOAA-TM-NMFS-SWFC-60, dated May 1986, by Paul Smith and Daniel Goodman. As first proposed by NMT in 1987, the tag does intelligent onboard data processing to reduce memory requirements. The tag extracts from each day's measured data and records in a "day log" the comparatively small amount of information required to fix position, plus some additional diagnostic information such as noon light intensity and water clarity. The resulting day log is compact enough so that it can log every day of a multi-year mission and never lose data for lack of memory space.

Either NMT or the user can handle the tasks of initially setting parameters and of reading data from a recovered tag. Host software running on an IBM(TM) compatible desk computer communicates with the tag through an adapter to do either task. The resulting data file is initially in compact binary form, maximum 257K, which is easy to handle and store. A second program translates the compact data record into a pair of printable report files. A third program provides graphical display of the compact data for easy browsing, and generates various kinds of graphical output.



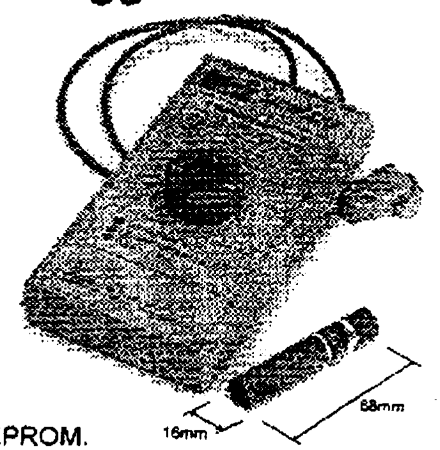
P.O. Box 427 Ben Nevis Road Shaw Island Washington U.S.A. 98286
Phone (206) 468-3375 FAX (206) 468-3844 Tax I.D. No. 22-1935793

**Specifications:**

| | |
|---|---|
| Dimensions | 16mm diameter, 100mm long. Stalk diameter 2.2 mm |
| Length of sensor stalk (light and external temp.) | User's choice, minimum 30mm. Samples have 200 mm stalks. |
| Weight | 52 g |
| Surface materials | Teflon(TM), 316 Stainless steel, silicone rubber |
| Nominal battery life | > 7 years |
| Size of data memory | 256 K Bytes |
| Temperature range | -40 to +85 °C |
| Range for full accuracy | -5 to 35 °C |
| Resolution | 0.2 °C |
| Response time | 2.3 sec to 37% |
| Clock compensation | 48 sec/year (1/5 degree/year) |
| Pressure range | 0 to 500M in time series, 0 to 765M in histogram |
| Resolution | 1 M from 0 to 126 M, then 3 M |
| Light measurement range | 5.5 decades down from noon sun |
| Resolution | 17% (15 points/decade) |
| Wavelength response | 450nM ±50nM |
| Measurement interval | 128 seconds, 675/day |
| Time series log interval | User-selectable multiple of measurement interval. |
| Data logged | • Histograms of all data.<br>• Day log contains basic position fixing data:<br>1. times of sunrise and sunset,<br>2. temperatures at surface, 61 M and 122 M,<br>3. noon light, clarity, and additional diagnostic data.<br>• Time series log contains:<br>1. light<br>2. internal temperature<br>3. external temperature<br>4. pressure. |
| Communication | Via NMT adapter to IBM(TM) compatible PC. |
| Data file formats | Compact binary for storage<br>Printable decimal report files<br>Windows metafile graphics |

Appendix (5)

# Minilog - Temperature & Depth Logger



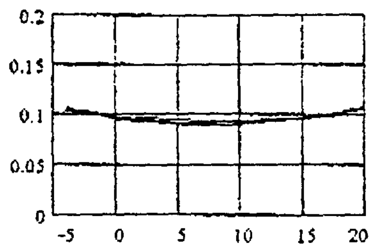

The Minilog is a microprocessor controlled data logger that stores data in non volatile memory which has a data retention time of 20 years. Data is read from the logger by a personal computer interface using infrared light. The Sample Period ranges from 1 second to 6 hours giving a deployment time from 2¼ hours to 5 years. The Minilog is powered with a lithium cell which can power the logger for up to 5 years. The protruding stainless steel probe has a 30 second time constant.

## *Minilog-TX/TR Specifications* [TEMPERATURE vs TIME LOGGER]

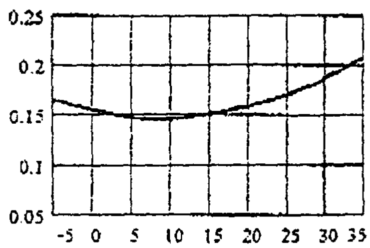
| | |
|---|---|
| Memory: | 8064 Temperature readings stored in nonvolatile EPROM. |
| Data Retention: | 20 years. |
| Battery Life: | 5 years or 1000 full deployments. [-TX version has non-replaceable battery] [ -TR version has factory replaceable battery] |
| Logging Interval: | 1 second to 6 hours. |
| Logging Duration: | 2¼ hours to 5 years. |
| Temperature Range: | Factory preset to one of the following:<br>-5 to 20 °C; 0.1 °C resolution; ± 0.2 °C accuracy.<br>-4 to 35 °C; 0.2 °C resolution; ± 0.3 °C accuracy. |
| Thermal Time Constant: | 30 seconds in stirred liquid. |
| Pressure Case: | Epoxy cylinder 16 mm by 68 mm. [-TR version is PVC cylinder, 21mm by 100mm] |
| Maximum Depth: | 1000 meters. |
| Weight: | -TX version 23 g in air, 10 g in water [ -TR version 41 g in air, 12 g in water] |
| Communication link: | Infrared LED. No external electrical connections. Full memory downloads in 3 minutes. |

### *Standard Temperature Ranges and Resolution*

The temperature resolution depends on the range of temperature the Minilog can record. The following graphs show the resolution for a -5 to 20 °C Minilog and a -5 to 35 °C Minilog.



-5 to 20 °C Minilog



-5 to 35 °C Minilog

## *Minilog-TDX/TDR Specifications* [TEMPERATURE & DEPTH vs TIME LOGGER]

Same as -TX/TR above with the following changes:

| | | | | |
|---|---|---|---|---|
| Memory: | 8128 Temperature and 8128 Depth readings stored in nonvolatile EEPROM. | | | |
| Maximum Depth: | Sensor Full Scale Depth + 50%. | | | |
| Battery Life: | 5 years or 700 full deployments. -TDR version has factory replaceable battery.<br>Communication link:Infrared LED. Full memory downloads in 6 minutes. | | | |
| Depth Range: | Factory preset to one of the following: | | | |
| | 50 psi | (34 meters, | 0.2 m resolution, | ± 1 m accuracy) |
| | 100 psi | (68 meters, | 0.4 m resolution, | ± 2 m accuracy) |
| | 200 psi | (136 meters, | 0.8 m resolution, | ± 4 m accuracy) |
| | 300 psi | (204 meters, | 1.2 m resolution, | ± 6 m accuracy) |
| | 500 psi | (340 meters, | 3 m resolution, | ± 7 m accuracy) |

## Minilog-PC Interface specifications

Minilog-PC includes interface unit, 6' of cable, DB-9 connector, and menu driven graphics software that runs on IBM/AT or compatible. The software is provided on 3½ inch and 5¼ inch diskettes. An internal 9 volt battery is user replaceable.

## Minilog software overview

*Initialize a New Study:* A text string may be entered to describe the study. A Sample Period from one second to 6 hours is chosen, and an optional delayed start selected. When the Minilog is removed from the interface in recording mode the LED flashes once every 10 seconds and can be viewed to confirm operation at any time.

*Delayed Start*: Choosing the Delay Start button allows you to initialize the Minilog at some future time. This is useful for starting a number of Minilog's at the same time. When the Minilog is in delay mode the LED flashes once every 5 seconds until the start time is reached then flashes every 10 seconds.

*Load Data From a Minilog:* The program offloads data from the Minilog and stores it in a binary file on disk. The file name is based on the Minilog serial number and is stored in the default data directory.

*Process Data:* You can either graph the data or create an ASCII file that can be read by a DOS editor or spreadsheet program. The graph defaults to the start and stop times and the minimum and maximum temperatures the Minilog can record. The graph may be zoomed to a user selected range.

## Ordering Information

*Minilog-PC* Minilog Interface to initialize and offload data from the Minilog. Includes a serial cable with a DB-9 connector, and menu driven software for an IBM\PC\AT or compatible.

*Minilog-TX* Temperature recording Minilog housed in an epoxy cylinder ( 16 mm diameter by 70mm length). The Minilog can be fastened with the nylon wire tie loop on the non sensor end. This model uses a thin wall tubing for minimum diameter small enough for a fish tag. For a more robust casing order the -TR below. The 5 year battery is not replaceable.

*Minilog-TR* Temperature recording Minilog housed in a PVC cylinder (21 mm diameter by 100mm length). Same as -TX model except that the casing will withstand more abuse. A 1/4" hole in the non sensor end allows attachment. The 5 year life battery can be replaced at the factory.

*Minilog-TDX* Temperature and Depth recording Minilog housed in a solid epoxy cylinder (16mm diameter by 70mm length). This model uses a thin wall tubing for minimum diameter small enough for a fish tag, for a more robust casing order the -TDR below. A nylon loop on one end is provided for attachment. The 5 year battery is not replaceable.

*Minilog-TDR* Temperature and Depth recording Minilog housed in a PVC cylinder ( 21mm diameter by 100mm length). The Minilog can be fastened with the mounting hole in one end. The 5 year battery can be replaced at the factory.

*Specify which of the two standard temperature scales are required:*

-5 to 20 °C (0.1 degree resolution)
-5 to 35 °C (0.2 degree resolution)

*For TDX and TDR types specify which of the five Full Scale Depth ranges are required:*

34, 68, 136, 204, or 340 meters.

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Appendix (6)

Wildlife Computers

**June 1991**
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## Geolocating Option for Mk3+, Mk3e, and Mk5 Time-Depth recorders

Wildlife Computers is pleased to announce a new option that is available on our Mk3+ Time-Depth-Recorders. For want of a better name we are calling it the Geolocation Option.

This option collects a light-level and seawater temperature reading when the animal surfaces and stores them into memory. Upon recovering the TDR these data are retrieved and fed into a program which displays them on your computer screen. The rate of change of light level when the sun is rising or setting is quite rapid, and in an interactive manner the program and user are able to determine the times of sunrise and sunset. These times are then used to calculate daylength and local-apparent-noon which can be fed into standard navigational formulae to calculate latitude and longitude.

The precision of the location estimate depends on several factors:

1) The rate of sampling of the depth data (light level and seawater temperature are only measured when the TDR is taking a depth reading).
2) The pattern of the animal's diving (long dives mean that sunrise and/or sunset may occur while the animal is at depth and these times will have to be determined by interpolation).
3) The time of year (at the spring and fall equinoxes daylength is the same throughout the world and thus the latitudinal location estimate has no accuracy).
4) The general position of the animal (polar latitudes yield more precision than equatorial latitudes except when there is no sunrise or sunset).

In addition, the algorithms currently used to calculate daylength and noon assume that the study animal has not moved between sunrise and sunset. Despite these potential sources of error, locations with an accuracy of $\pm$ 60 nautical miles are generally achievable. The sea-surface temperature data may be used in conjunction with satellite imagery to improve the location estimate, particularly the latitude estimate close to the equinoxes.

For animals that stay within a circumscribed, known area, the Geolocation function would not be of interest, but if your study animal goes to sea on foraging trips for weeks or months at a time and is not behaviorally suited to tracking by satellite, then this feature may provide new and exciting information about where he (or she) is going. And with the TDR sampling depth and possibly temperature in its usual manner, you suddenly have the ability to know not only where your animal went but what he (or she) was doing while there.

Adding the Geolocation Option to our Mk3+/Mk3e TDR requires our titanium or heavy-duty aluminum pressure housing fitted with a special lexan end-cap, a light-level-sensor, and a temperature sensor. The Geolocation option comes standard on our Mk5 TDR. A small amount of additional memory (4 bytes per dive) is used to record the geolocation data. In addition, the user will require an accurate watch for setting the time on the TDR.

We also offer our GEOLOCATION analysis software package. This software processes the geolocation (light-level and temperature) data recorded by the TDR's Geolocation option.

The light-level and temperature data are extracted from the hexadecimal listing file created by the TDR, and displayed graphically on a day-by-day basis. The times of dawn and dusk for each day are determined interactively, and are used to calculate daylength and local-apparent-noon. Daylength and the time of local-apparent-noon are fed into an algorithm that uses standard navigational formulae to calculate the daily latitude and longitude. The calculated positions, along with the surface-seawater temperature, are written to an ASCII file, which can be read into database, plotting, or statistical analysis programs. The price of the GEOLOCATION analysis software is US$200.00.

Please contact us for more details about the program and the limits of this technique of geolocation.

Wildlife Computers

September 1991

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# Microprocessor-controlled Time-Depth Recorder - Mk5

The Mk5 Time-Depth Recorder (Mk5 TDR) is the smallest microprocessor-controlled time-depth recorder that Wildlife Computers has produced to date. This specialized miniature computer, cast in epoxy, is designed to gather data on both the diving behavior and location of the study animal. The Mk5 has three data channels (depth, environmental temperature, and light intensity) as standard, and the sampling of all three is controlled by user-defined sampling protocols (a sampling protocol defines the channel and time interval for data sampling; you may choose to sample one, two, all three or none of the channels). Location can be determined by light intensity readings; the geolocation option on the MK5 TDR allows you to set parameters to control the gathering of these light intensity readings independent from the sampling protocols. You therefore have the flexibility to gather dive data and/or location data, as your application dictates. The sampling protocols and geolocation parameters are established prior to deployment, and can be easily changed between projects or deployments. A personal computer is used to enter the parameters, and for recovery of the data onto a diskette or hard disk for subsequent analysis. Wildlife Computers additionally can supply analysis software to help you decode, format, and analyze the recovered data (**Dive-Analysis** and **Strip-Chart**), and calculate daily position from the light intensity readings (**Geolocation**).

The Mk5 TDR is custom-made to your specifications, however, unlike the Mk3+ TDR, this model cannot be modified once cast in epoxy. We recommend the Mk5 TDR for applications where size and weight are critical.

<u>Hardware Features:</u>

- The components of the Mk5 TDR are cast in an epoxy block
  - size is 6.4cm × 3.8cm × 1.3cm (2.5 × 1.5 × 0.5 inches)
  - total weight (including all components) is 50g (1.8 ounces)
- The Mk5 TDR is powered by a non-replaceable lithium battery. This battery, based upon the measured low power consumption of the TDR, should provide enough power for 10 years of seasonal use.
- 128 KBtyes of memory is standard; one byte of memory is used per reading. The 128K memory chip can optionally be replaced by a 512 KByte memory chip. Please contact us, however, for information on maximizing memory usage.
- The Mk5 has three standard channels.
  - A depth channel which has one of the following depth ranges:
    - 0-250m (resolution 1m) 0-1250m (resolution 5m)
      0-500m (resolution 2m) 0-1500m (resolution 6m)
      0-750m (resolution 3m) 0-1750m (resolution 7m)
      0-1000m (resolution 4m)
    - A titanium pressure transducer provides excellent corrosion resistance.
  - A temperature channel, which measures environmental temperature. Its range is -2.5°C to +22.7°C, with a resolution of ±0.1°C, and accuracy of ±0.5°C.
  - A light intensity channel, which records relative light levels.